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Evaluation of productivity and quality of common wheat (*Triticum aestivum* L.) and spelt (*Triticum spelta* L.) in relation to nutrition conditions

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Abstract

Field experiments were conducted at the Joniškėlis Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry during 2009–2012. The study was aimed to explore the effects of the ecological fertilizer Ekoplant and the bio-activators Biokal 01 and Terra Sorb Foliar on the formation of the productivity elements, grain yield and quality of spelt (*Triticum spelta* L.) cv. 'Franckenkorn' and common wheat (*Triticum aestivum* L.) cv. 'Toras' in an organic cropping system on an clay loam *Endocalcari-Endohypogleyic Cambisol* (*CMg-n-w-can*). The weather conditions, especially those during crop wintering, differed between years and this affected the grain yield of both winter wheat species and resulted in different fertilizer efficacy. In 2010 and 2012, the winter wheat crops overwintered well and the yield of common wheat was by 27.6% and 30.1%, respectively higher than that of spelt. In 2011, due to the contrasting winter conditions with a spell of unusually high temperatures in January followed by a sharp drop of temperature to −25°C the crop of common wheat thinned out more than spelt, which resulted in a significantly lower common wheat grain yield. In 2010 and 2011, the application of ecological fertilizer Ekoplant as well as in combination with Biokal 01 and Terra Sorb Foliar led to an increase in the values of biometric indicators, i.e. stem mass, ear length and mass, grain number per ear significantly increased having used Ekoplant fertilizer in combination with Terra Sorb Foliar. However, in 2012, Biokal 01 exerted the most marked positive effect on the biometric indicators of wheat. The highest yield increase for both wheat species was observed when Ekoplant fertilizer had been used in combination with the bio-activator Biokal 01. The Ekoplant fertilizer as well as in combination with the bio-activator Biokal 01 did not have any significant effect on grain quality indicators, while the bio-activator Biokal 01 increased the protein and gluten content by 2.2% and 3.4%, respectively.

Key words: bio-activators, common wheat and spelt, ecological fertilizer, productivity elements, quality, yield.

Introduction

In Lithuania, like in many European countries, the agricultural policy is oriented towards organic farming, whose prime objective is to solve environmental and food safety problems. The steadily growing demand for organic production and increasing area of organically-managed crops are the factors that encourage testing and choice of the available cultivars and development of new cultivars tailored for organic production. Organic producers give their preference to competitive crops and cultivars, with high disease resistance and high competitive power against weeds (Ostergard, Jensen, 2004).

The wheat (*Triticum*) genus includes many species, three of which – common (*Triticum aestivum* L.), durum (*Triticum durum* Desf.) and spelt (*Triticum spelta* L.) are spread worldwide (Sliesaravičius et al., 2006). The common wheat (*Triticum aestivum* L.) is the most common species on a global scale and is most suitable for bleak Lithuanian climate; however, its grains have lower protein and nutrient contents (Keller et al., 1999; Wiwart et al., 2004; Kohajdova, Karovicova, 2008). Durum wheat (*Triticum durum* Desf.) has high grain protein content. It is a warmer-climate crop, cultivated in southern countries – Italy, Spain, the USA, Egypt and others. In Lithuania, durum wheat is not cultivated because of adverse climate conditions. Spelt (*Triticum spelta* L.), an ancient wheat species, cultivated in ancient Egypt and Italy, is becoming increasingly popular in Lithuania. The main centres of spelt cultivation in Europe are southern part of Germany and Switzerland (Mielke, Rodemann, 2007). Spelt is an alternative crop, growing without any special demands for soil as well as climate (Rüegger et al., 1990; Sliesaravičius et al., 2006; Schober et al., 2006). Spelt is well adapted to growing in a wide range of conditions. In favourable conditions, it can produce yields similar to those of common wheat (Laghetti et al., 1999; Burgos et al., 2001). Despite several drawbacks (brittle stems, difficult de-hulling), this wheat has many valuable traits. Even at low fertilization level, spelt grains have higher contents of protein (16–17%), nutrients and minerals compared to common wheat (Keller et al., 1999; Moudrý, Dvoráček, 1999; Smolková et al., 2000; Wiwart et al., 2004; Kohajdova, Karovicova, 2008). Spelt is used for the production of various foods: pasta, granolas, flakes and bread. Development of spelt cultivation technology has been started only recently.

There is little experimental evidence on the efficacy of certified ecological products for the productivity of spelt and common wheat, especially in an organic cropping system. Biokal 01 applied in winter wheat and rye crops was found to give a significant grain yield increase (Sliesaravičius et al., 2006; Pekarskas, Stelmokas, 2009). Organic farming does not allow the use of conventional mineral fertilizers and crop protection products. As a result, in our experiments we applied Ekoplant fertilizer, certified for wheat productivity increasing in an organic production system and bio-activators Biokal 01 and Terra Sorb Foliar. Properly used fertilizers help plants survive adverse climate conditions and make them more resistant to diseases and pests.

The current study was aimed to ascertain the effects of ecological fertilizer and bio-activators on common and spelt wheat overwinter survival, development and productivity.

Materials and methods

Field experiments. Field experiments were carried out in a certified ecological field, at the Joniškėlis Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry during 2009–2012. The soil of the experimental site is clay loam *Endocalcari-Endohypogleyic Cambisol* (*CMg-n-w-can*) with a humus content of 2.1–2.3%, pH_{KCl} – 6.9–7.0, P_2O_5 – 186–200 mg kg^{-1}, K_2O – 255–260 mg kg^{-1}.

Experimental design. The two-factor experiment included four replications. Factor A – species of winter wheat: spelt (*Triticum spelta* L.) cv. ‘Franckenkorn’ and common wheat (*Triticum aestivum* L.) cv. ‘Toras’. Factor B – ecological fertilizer Ekoplant, bio-activators Biokal 01 and Terra Sorb Foliar and their combinations. Before sowing, spelt seeds were treated with bio-activator Biokal 01 10 l ha^{-1}. Factor B: 1) without fertilizer, 2) Terra Sorb Foliar 1.5 l ha^{-1} at tillering stage (BBCH 24), 1.5 l ha^{-1} at booting stage (BBCH 32), 2.0 l ha^{-1} at ear emergence stage (BBCH 52) (TSF), 3) Ekoplant 250 kg ha^{-1} in the autumn before sowing, Terra Sorb Foliar 1.5 l ha^{-1} – at tillering stage (BBCH 24) (E + TSF), 4) Biokal 01 – 10.0 l ha^{-1} at tillering (BBCH 24), booting (BBCH 32) and ear emergence (BBCH 52) stages (B01), 5) Ekoplant – 250 kg ha^{-1} in the autumn before sowing, Biokal 01 – 10.0 l ha^{-1} at tillering stage (BBCH 24) (E + B01), 6) Ekoplant – 250 kg ha^{-1} in the autumn before sowing (E).

Ekoplant is a complex, powdery, non-chloride potassium-phosphorus-magnesium fertilizer of natural origin. It contains micro and macro-elements. The main active ingredient, in the form of carbonates and sulphates, is potassium, which is readily and rapidly assimilated by plants. Ekoplant fertilizer strengthens plant immune system and increases resistance to inimical environmental conditions. Its chemical composition: phosphorus content (P_2O_5) – 8%, potassium content (K_2O) – 23%, and sulphur content (SO_3) – 12%; macroelements: magnesium oxide (MgO) – 9%, calcium oxide (CaO) – 10%; microelements: copper (Cu) – 30 mg kg^{-1}, zinc (Zn) – 50 mg kg^{-1}, manganese (Mn) – 60 mg kg^{-1}, boron (B) – 50 mg kg^{-1}.

Terra Sorb Foliar, a liquid bio-activator, is a complex of amino acids and microelements designed for additional foliar fertilization. It improves resistance of crops and recovery from stress, stimulates pollination and fruit setting processes, improves absorption of nutrients and their mobility within a plant. The free amino acids activate the photosynthesis, increase the chlorophyll content and affect important vital functions of the crop. The composition of Terra Sorb Foliar: amino acid content – 12%, free amino acids – 9.3%, organic nitrogen (N) – 2.1%, B – 0.019%, Mn – 0.046%, Zn – 0.067%.

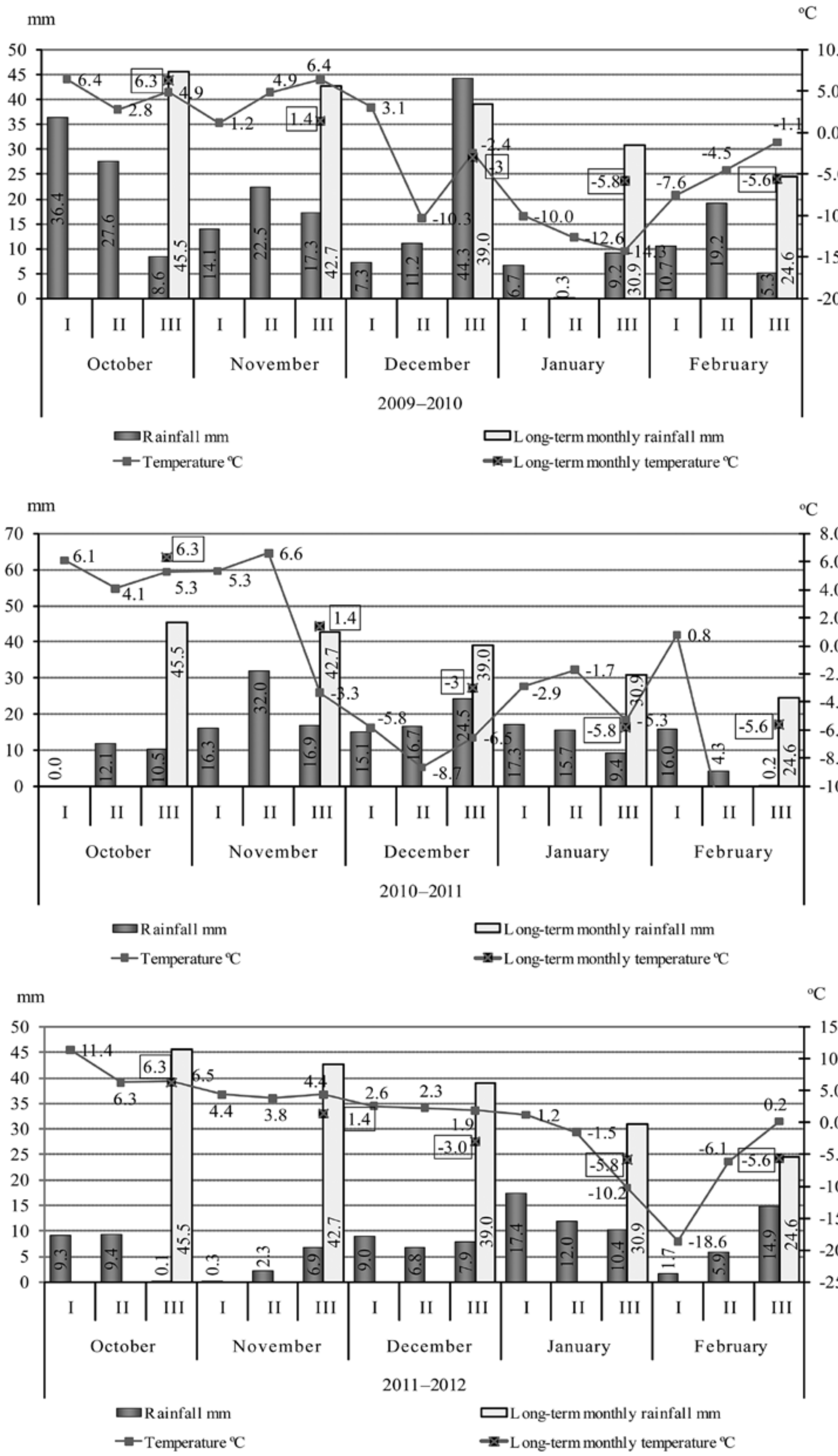
Biokal 01 is a liquid organic bio-activator, which improves crop root system and assimilation of macro and microelements from the soil, because of which crops become more resistant to adverse environmental conditions. Moreover, microelements from the bio-activator affect macro-elements in the soil and improve their assimilation. Chemical composition of Biokal 01: N – 16.6%, P_2O_5 – 26.7%, K_2O – 34.7%, calcium (Ca) – 7.9%, magnesium (Mg) – 2.2%, iron (Fe) – 0.7%, carbon oxide (CO) – 3.6%, Cu – 7.2%, selenium (Se) – 0.4%. Extracts of medicinal plants present in the composition of Biokal 01 as well as volatile oils perform a phyto-sanitary role – block the spread of fungous and other diseases and repel many types of pests.

Fertilizer Ekoplant, certified for organic farms, was spread in the autumn before wheat sowing and bio-activators Biokal 01 and Terra Sorb Foliar were applied according to the experimental design: in spring, at winter wheat tillering, booting and ear emergence stages.

Crop development and productivity research was done at the Joniškėlis Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry. After full emergence of winter wheat, four 0.25 m^2 areas were marked in each plot and the number of plants was identified in them. At the end of the growing season, 20 winter wheat plants were sampled from each plot (0.25 m^2 in size) for biometrical measurements (stem length and mass, ear length and mass, grain number and mass per ear). Unhulled ears were detached from stems, then measured and weighed. Afterwards, the grains were hulled from ears, counted and weighed. Winter wheat grain yield was measured by weighing and adjusted to 15% standard moisture. The plots were harvested by a small-plot combine harvester “Sampo Rosenlew 500” (“W. Rosenlew Ab”, Finland) after complete maturity of wheat (BBCH 89); the yield from each field was weighed separately.

Laboratory analyses of the grain quality were done at the laboratory of Plant Pathology and Protection Department, Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry. Protein, starch, gluten contents in grain were measured by a grain analyzer “Infratec 1241 Foss” with a calibration package IM 9200 (“Foss”, Denmark).

Meteorological conditions. Description of the weather conditions was based on the data from the meteorological site of Joniškėlis Experimental Station. In 2010, the winter was cold, but where there was snow, the winter wheat crops overwintered well (Fig. 1). In 2010, high precipitation level had a positive effect on the whole period of growth because clay soils have a high capillary moisture capacity (Tausojamoji žemdirbystė..., 2008).

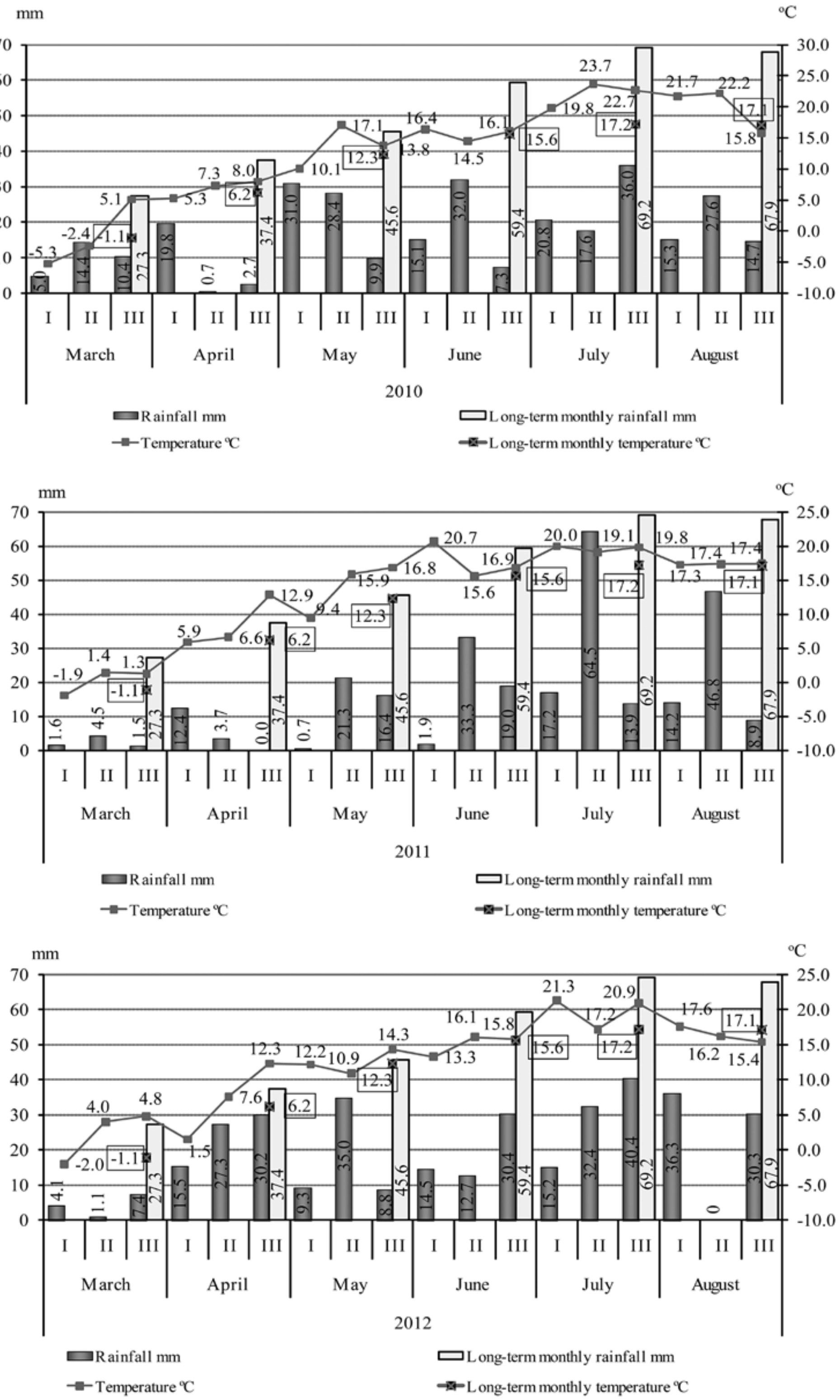


Joniškėlis Experimental Station, 2009–2012

Figure 1. Meteorological conditions of winter wheat wintering period

The autumn of 2010 and 2011 was dry. As a result, emergence and development of winter wheat were slow. In 2010, the winter was changeable and relatively high temperatures were observed in January. In the winter of 2012, the average daily temperature was close to the multi-year average and the precipitation rate was low. Both species exhibited a good over winter survival rate.

In the spring of 2010, the average daily temperature was close to the annual rate, precipitation rate in March and May was by 2.5 and 23.7 mm higher, respectively (Fig. 2). The spring of 2011 and 2012 was dry, average monthly temperature of March was by 0.8 and 3.8 °C, respectively higher than the multi-year average.



Joniškėlis Experimental Station, 2010–2012

Figure 2. Meteorological conditions of winter wheat growing season

Statistical analysis. The significance of the experimental data was estimated by the analysis of variance (two-factor *ANOVA*) by evaluating the standard deviation and the least significant difference LSD_{05}. The inter-dependence of the research data was assessed by the correlation-regression analysis. Statistical analysis was performed using the statistical software package *SELEKCIJA* (Tarakanovas, Raudonius, 2003).

Results and discussion

Formation of the primary productivity elements and the over winter survival of plants. The data on the number of emerged winter wheat plants in autumn and spring are presented in Table 1. Nutrient utilization efficiency is strongly dependent on the initial crop stand density. An even crop stand, optimal number of plants per unit area allow them to rationally utilize nutrients present in the soil (Maikštėnienė et al., 2006). In our trials, in the autumn of 2009, 2010 and 2011, the number of emerged plants of both common wheat and spelt was close to the optimal in the plots of all experimental treatments (from 320 to 360 plants m[2]) (Seibutis et al., 2009). In the crops sown in 2009, due to the severe winter of 2010, only 50% of the plants survived the winter; however, the stand density remained sufficient to produce a normal yield. In the spring of 2010, the number of plants significantly depended on the winter wheat species grown. Averaged over all treatments' plots winter survival of common wheat was 60.4% and that of spelt was 46.7%. The difference between the number of plants was significant (F_{fact} = 75.81**, LSD_{05} = 10.36). In the second experimental year, the crops sown in the autumn of 2010, exhibited a markedly poorer over winter survival caused by the contrasting winter conditions, which is shown in Figures 1 and 2. A rise in temperature to +5°C at the end of January 2011, which melted the snow layer and triggered nutrient migration in plants, was followed by a sharp drop to −25°C, which resulted in severe plant kill. Moreover, a lengthy drought occurred in spring (the rate of rainfall in April and May was by 21.3 and 7.2 mm lower than the long-term mean) which aggravated the state of crops and caused a dramatic thinning of both common wheat and spelt crops. Although the winter of 2011–2012 was conducive to winter wheat over wintering, by spring, the number of spelt plants declined more (by 45%), compared with common wheat whose number of plants declined by 33%.

The autumn-applied Ekoplant fertilizer had no significant effect on the number of emerged plants of common wheat and spelt species; however, the number of plants in fertilizer-applied treatments was higher for average of both species compared with the unfertilized treatments. Seeking to incorporate the Ekoplant fertilizer, the plots of these treatments were additionally cultivated, which impacted on soil moisture and plant emergence. The crop that had received Ekoplant fertilization in the autumn had significantly more plants in spring only in 2011, compared with unfertilized crop; however, on average over both wheat types, the difference was insignificant (Table 1).

Table 1. Number of winter wheat plants

Joniškėlis Experimental Station, 2009–2012

Fertilization (factor B)	Winter wheat (factor A)						Mean factor B		
	2009		2010		2011				
	T. aestivum	*T. spelta*	*T. aestivum*	*T. spelta*	*T. aestivum*	*T. spelta*	2009	2010	2011
	Number of plants m^{-2} in autumn								
Without fertilizer	295	285	368	368	390	353	290.0	368.0	371.5
TSF	315	298	317	362	396	357	306.5	339.5**	376.5
E + TSF	289	292	318	375	393	378	290.5	346.5*	385.5
B01	308	289	333	346	384	342*	298.5	339.5**	363.0
E + B01	275	261	331	370	358	324**	268.0	350.5	341.0*
E	319	297	345	332	360	351	308.0	338.5**	355.5
Mean factor A	300.2	287.0	335.3	358.8**	380.2	350.8**	293.6	347.1	365.5
	Number of plants m^{-2} in spring								
	2010		2011		2012		2010	2011	2012
Without fertilizer	180	135**	38	62**	259.2	184.0**	157.5	50.0	221.6
TSF	182	146*	36	50	251.2	211.8**	164.0	43.0	231.5
E + TSF	184	128**	49	54	261.0	191.5**	156.0	38.5	226.3
B01	171	134**	62**	68**	259.5	187.8**	152.5	65.0*	223.7
E + B01	166	122**	66**	67*	250.8	187.5**	144.0	61.0	219.2
E	186	137**	33	60*	245.3	191.0**	161.5	41.0	218.2
Mean factor A	178.2	133.7**	43.5	56.0**	254.5	192.3**	155.9	49.8	223.4

* – $P < 0.05$, ** – $P < 0.01$

Biokal 01 application after resumption of vegetation in 2010 did not have any significant influence on the stand density. In the spring of 2011, there was a significant interaction between the two factors (A × B) (F_{fact} = 2.63*, LSD_{05} = 13.50).

Under unfavourable spring conditions of 2011, after the severe winter and lengthy drought in spring, in the plots of common and spelt wheat that had been applied with Biokal 01 after resumption of vegetation, the number of plants remained significantly higher compared with those not applied with Biokal 01, which on average over both species made up 30% more.

Secondary elements of crop productivity. Stem and ear length and mass are attributed to the secondary productivity indicators.

Stems. Winter wheat stem length significantly differed between the wheat species grown (in 2010 – F_{fact} = 69.28**, LSD_{05} = 4.57, in 2011 – F_{fact} = 397.65**, LSD_{05} = 3.90, and in 2012 – F_{fact} = 716.63**, LSD_{05} = 1.99). The highest stem height was recorded for spelt winter wheat, in 2010 it was 89.8–102.8 cm, in 2011 it was 81.10–85.43 cm, and in 2012 it was 122.3–127.7 cm, while the stems of common winter wheat in 2010 were shorter by up to 25%, in 2011 by up to 43% and 2012 by up to 21% (Table 2). Literature evidence suggests that common wheat stem length in normal weather conditions reaches 84.3–85.7 cm (Maikštėnienė et al., 2006; Tausojamoji žemdirbystė..., 2008). The stem length of spelt in 2010 was positively influenced by the fertilizer Ekoplant, bio-activator Biokal 01 and their combination. In the treatments applied with the ecological fertilizer, spelt stem length increased by 6.7%, in those applied with the ecological fertilizer in combination with bio-activator Biokal 01 by 4.8%, and in the treatments applied with bio-activator Biokal 01 three times at different wheat growth stages a 7.1% increase in stem length was achieved, compared with unfertilized treatments. In 2011, bio-activator Terra Sorb Foliar stood out by its efficacy in spelt wheat crop, where stem length increased by 4.2%, compared with the unfertilized crop. In 2012, having applied Ekoplant in combination with Terra Sorb Foliar or Biokal 01, the stem length of both common and spelt wheat increased by 1.7–2.8%, compared with the unfertilized treatments. The correlation regression analysis of common and spelt winter wheat grain yield and stem height showed a strong correlation for common wheat ($r = 0.87$, $p < 0.01$), while for spelt wheat it was moderate ($r = 0.66$, $p < 0.01$).

Table 2. The effect of organic fertilizer and bio-activators on winter wheat stems
Joniškėlis Experimental Station, 2010–2012

Fertilization (factor B)	Winter wheat (factor A)						Mean factor B		
	2010		2011		2012				
	T. aestivum	*T. spelta*	*T. aestivum*	*T. spelta*	*T. aestivum*	*T. spelta*	2010	2011	2012
Stem length cm									
Without fertilizer	82.2	95.5*	51.4	81.8**	97.8	124.9**	88.85	66.62	111.4
TSF	78.1	89.8	52.3	85.4**	96.4	123.3**	83.95	68.84	109.9
E + TSF	76.8	93.1	48.3	82.0**	99.5	127.7**	84.95	65.10	113.6
B01	77.4	102.8**	47.1	81.1**	101.0	126.9**	90.10	64.10	113.9
E + B01	76.6	100.3**	48.8	83.5**	100.6	127.2**	88.45	66.14	114.0
E	80.8	102.4**	51.3	85.3**	100.2	122.3**	91.60	68.30	111.3
Mean factor A	78.65	97.32**	49.85	83.18**	99.3	125.4**	87.99	66.52	112.4
Stem mass g									
Without fertilizer	1.33	1.23	0.96	1.83**	1.51	2.12**	1.28	1.40	1.82
TSF	1.44	1.35	1.22	1.97**	1.68	1.97*	1.40	1.60	1.83
E + TSF	1.51	1.35	1.10	2.08**	1.56	2.03**	1.43	1.59	1.80
B01	1.47	1.28	1.07	1.90**	1.59	2.29**	1.38	1.49	1.94
E + B01	1.25	1.51	0.96	2.09**	1.50	2.34**	1.38	1.53	1.92
E	1.51	1.61	1.19	1.94**	1.65	2.01*	1.56*	1.57	1.83
Mean factor A	1.42	1.39	1.08	1.97**	1.58	2.13**	1.41	1.53	1.86

* – $P < 0.05$, ** – $P < 0.01$

Meanwhile, stem mass in 2010 significantly differed not only from the unfertilized treatment, but also there were differences between fertilizer and bio-activator treatments ($P \leq 0.01$); however, the interaction of both factors (A × B) was weak ($F_{fact} = 0.95$, $LSD_{05} = 0.37$).

In 2010, Ekoplant fertilizer tended to increase stem mass in the plots of all treatments; for spelt it increased by 23.6%, for common wheat by 11.9%, compared with the unfertilized ones. However, in the treatments applied with the bio-activator Terra Sorb Foliar three times at different growth stages, stem mass increased by 8.9% and 7.6%, and in those applied with *Biokal* 01 the stem mass increase amounted to 3.9% and 9.5%, respectively.

In 2011, there were established significant differences ($P \leq 0.01$) in stem mass between the winter wheat species grown ($F_{fact} = 211.07^{**}$, $LSD_{05} = 0.14$). The stem mass of spelt was approximately 50% higher compared with common wheat. Stem mass of common wheat increased by 21% having used bio-activator Terra Sorb Foliar three times at different growth stages and the application of Ekoplant in combination with Biokal 01 increased spelt stem mass by 12.4% compared with the unfertilized crops. The literature data indicate that optimal stem mass for common winter wheat is 1.08–1.56 g (Maikštėnienė et al., 2006).

In 2012, the stem mass of spelt was significantly higher than that of common wheat ($F_{fact} = 50.36^{**}$, $LSD_{05} = 0.16$) ($P \leq 0.01$). The stem mass of common wheat considerably increased (by 10%) having applied the bio-activator Terra Sorb Foliar three times at different wheat development stages, while for spelt the increase amounted to 9%, having applied Ekoplant in combination with Biokal 01, compared with the unfertilized treatments.

The correlation regression analysis of common and spelt winter wheat grain yield and stem mass and ear mass showed a moderate correlation ($r = 0.52$, $p < 0.01$) for common wheat, while for spelt wheat the grain yield did not depend on ear mass ($r = 0.17$, $p < 0.01$).

Ears. Winter wheat ear length in 2010 significantly differed between wheat species ($F_{fact} = 50.01^{**}$, $LSD_{05} = 0.42$) and ecological fertilizer and bio-activators used ($F_{fact} = 3.77^{**}$, $LSD_{05} = 0.73$), moreover, the interaction between both factors was significant ($F_{fact} = 2.50^{*}$, $LSD_{05} = 1.03$). The ears of spelt were longer and reached up to 9.7 cm. Significant influence on ear length was exerted by the Ekoplant fertilizer applied alone (an increase in ear length was 21.6%) and in combinations with the bio-activators Biokal 01 (21.6%) and Terra Sorb Foliar (20.0%) (Table 3). Having used the bio-activator Biokal 01 three times at different wheat growth stages, ear length increased by on average 0.9 cm, and having used Terra Sorb Foliar – by 2.1 cm. Ear length of common winter wheat differed less between the treatments: in the treatments applied with bio-activators, ear length was by 0.2–0.3 cm higher and in the treatments applied with the ecological fertilizer by up to 0.6 cm. In 2011, ear length significantly differed between winter wheat species and ecological fertilizer and bio-activators used ($F_{fact} = 6.94^{**}$, $LSD_{05} = 0.87$). Spelt ear length was most markedly influenced by the Ekoplant fertilizer in combination with the bio-activator Terra Sorb Foliar (12.3% longer), while the highest ear length of common wheat was recorded in the treatments applied solely with Ekoplant fertilizer (6.5% longer compared with unfertilized). Analysis of the ear length data from the 2010–2011 period revealed significant differences only between wheat species

(F_{fact} = 50.36**, LSD_{05} = 0.70). In 2011, common wheat ears were by on average 21% longer and those of spelt wheat by 29%. Although in 2012 spelt ear length was significantly greater (by 18%) than that of common wheat (F_{fact} = 69.15**, LSD_{05} = 0.37), the difference was smaller than in previous experimental years. The ear length of spelt was most markedly positively influenced by the ecological fertilizer Ekoplant (by 5.3%), and that of common wheat by the bio-activator Biokal 01 by 1.1%. The results of ear length of common winter wheat determined in 2004–2005 research were closer to those from the year 2010 and 2012 and made up 7.3–8.0 cm (Maikštėnienė et al., 2006).

Table 3. Ear length and mass of winter wheat as affected by organic fertilizer and bio-activators
Joniškėlis Experimental Station, 2010–2012

Fertilization (factor B)	Winter wheat (factor A)						Mean factor B		
	2010		2011		2012				
	T. aestivum	*T. spelta*	*T. aestivum*	*T. spelta*	*T. aestivum*	*T. spelta*	2010	2011	2012
Ear length cm									
Without fertilizer	7.4	7.6	9.4	12.4**	7.1	8.8**	7.50	10.83	7.95
TSF	7.7	9.7**	10.0	12.3**	6.7	8.0	8.70**	11.12	7.35*
E + TSF	8.0	9.5**	10.0	14.2**	7.0	8.6**	8.75**	12.04*	7.80
B01	7.6	8.5*	9.7	12.6**	7.0	8.9**	8.05	11.11	7.95
E + B01	7.4	9.7**	9.3	13.1**	7.2	8.7**	8.55**	11.22	7.95
E	7.8	9.7**	10.0	12.0**	7.5	8.8**	8.75**	11.00	8.15
Mean factor A	7.65	9.12**	9.69	12.77**	7.08	8.63**	8.39	11.23	7.86
Ear mass g									
Without fertilizer	1.96	1.34**	2.04	2.73*	1.49	1.75*	1.65	2.39	1.62
TSF	1.92	1.63	2.67*	2.95**	1.52	1.60	1.78	2.81	1.56
E + TSF	2.16	1.75	2.39	3.32**	1.52	1.64	1.96*	2.86	1.58
B01	2.08	1.53*	2.37	3.03**	1.70	1.78*	1.81	2.70	1.74
E + B01	1.90	1.85	2.35	3.23**	1.47	1.95**	1.88	2.79	1.71
E	2.12	1.83	2.57	2.86*	1.56	1.65	1.98*	2.72	1.61
Mean factor A	2.02	1.66**	2.40	3.02**	1.54	1.73**	1.84	2.71	1.64

* – $P < 0.05$, ** – $P < 0.01$

Winter wheat ear mass in 2010 significantly differed between the winter wheat species grown (F_{fact} = 20.57**, LSD_{05} = 0.17); however, the interaction of both factors was weak (F_{fact} = 1.08, LSD_{05} = 0.41). The ear mass of common winter wheat was by 17.8% higher than that of spelt. Ear mass was significantly increased by Ekoplant fertilizer applied alone and in combination with the bio-activator Terra Sorb Foliar, by 7.5% and 9.3%, respectively compared with the unfertilized. In 2011, ear mass significantly differed between the winter wheat species grown (F_{fact} = 26.16**, LSD_{05} = 0.24). Spelt ears were by on average 21% heavier than those of common wheat. The ear mass of common wheat was most considerably influenced by a three-time application with the bio-activator Terra Sorb Foliar at different growth stages. This treatment's ears were 0.63 g heavier than those of the unfertilized treatment. The highest ear mass of spelt was achieved in the treatment applied with Ekoplant fertilizer in combination with the bio-activator Terra Sorb Foliar, where the ears were 0.59 g heavier compared with the untreated. In 2012 like in 2011, spelt ear mass was significantly greater than that of common wheat (F_{fact} = 13.89, LSD_{05} = 0.10). Spelt ear mass was most markedly (by 10.3%) increased by the ecological fertilizer Ekoplant in combination with the bio-activator Biokal 01, while common wheat ear mass was most considerably (by 12.4%) enhanced by the bio-activator Biokal 01 used three times at different wheat development stages.

In 2011, when the weather conditions were adverse for growth and tillering, in a thinner crop plants produced a higher number of grains per ear. The data provided in Table 4 show that the number of grains per ear for spelt cv. 'Franckenkorn' compared with that of common wheat cv. 'Toras' in 2010 was lower by 32%, in 2011 by 29%, in 2012 by 14%. Also, grain mass per ear in 2010 for spelt cv. 'Franckenkorn' was by about 40% lower compared with the common wheat cv. 'Toras'; however, in 2011 spelt grain mass was by 14% higher than that of common winter wheat. In 2012, the differences in grain mass per ear between the wheat species were smaller than in previous years. Grain number and mass per ear significantly depended on the winter wheat species grown (in 2010 – F_{fact} = 94.35**, LSD_{05} = 2.67, F_{fact} = 40.61**, LSD_{05} = 0.13; in 2011 – F_{fact} = 59.38**, LSD_{05} = 4.35, F_{fact} = 8.65*, LSD_{05} = 0.99; in 2012 – F_{fact} = 36.32**, LSD_{05} = 1.32, F_{fact} = 0.12, LSD_{05} = 0.08). Since there was no significant interaction between the both factors (A × B), they were discussed as separate factors. Analysis of ear composition elements revealed significant differences when using Ekoplant fertilizer and its combination with the bio-activator Terra Sorb Foliar, the number of grains per ear for spelt increased by 7 grains and for common wheat by 1–4 grains in 2010. Meanwhile, grain mass per ear increased for spelt by 0.27–0.35 g, for common wheat by 0.13–0.22 g, respectively. A similar trend persisted in 2011, when grain number and mass per ear increased for common wheat having used Ekoplant fertilizer and Terra Sorb Foliar by 13 grains and 0.65 g and 11 grains and 0.54 g, respectively; while for spelt, grain number and mass per era increased having used Ekoplant in combination with the bio-activator Terra Sorb Foliar by 8 grains and 0.54 g, respectively. However, in 2012, common wheat grain number and mass per ear were more markedly increased by the bio-activator Biokal 01 by 6.7% and 12.9%, respectively and those of spelt were more significantly increased by Biokal 01 in combination with the ecological fertilizer Ekoplant by 11.1% and 11.3%, respectively, compared with the unfertilized treatments.

Table 4. Grain number and mass per ear of winter wheat
Joniškėlis Experimental Station, 2010–2012

Fertilization (factor B)	Winter wheat (factor A)						Mean factor B		
	2010		2011		2012				
	T. aestivum	*T. spelta*	*T. aestivum*	*T. spelta*	*T. aestivum*	*T. spelta*	2010	2011	2012
Grain number per ear									
Without fertilizer	39	22**	43	32	28	24*	30.5	37.5	26.0
TSF	38	28**	54*	35	28	23**	33.0	44.5	25.5
E + TSF	43	29**	50	40	28	23**	36.0*	45.0	25.5
B01	42	25**	51	37	30	24*	33.5	44.0	27.0
E + B01	36	29**	48	36	26	27	32.5	42.0	26.5
E	40	29**	56*	33*	28	24*	34.5	44.5	26.0
Mean factor A	39.7	27.0**	50.3	35.5**	28.0	24.2**	33.3	42.9	26.1
Grain mass per ear g									
Without fertilizer	1.54	0.97**	1.57	1.95	1.22	1.26	1.26	1.76	1.24
TSF	1.52	1.18**	2.11*	2.16*	1.26	1.17	1.35	2.14*	1.22
E + TSF	1.76	1.24	1.83	2.49**	1.25	1.18	1.50*	2.16	1.22
B01	1.64	1.09**	1.87	2.25*	1.40	1.30	1.37	2.06	1.35
E + B01	1.51	1.34	1.88	2.38**	1.21	1.42*	1.43	2.13	1.32
E	1.67	1.32	2.22*	2.14	1.27	1.20	1.50*	2.18	1.24
Mean factor A	1.61	1.19**	1.91	2.23*	1.27	1.26	1.40	2.07	1.27

* – $P < 0.05$, ** – $P < 0.01$

Yield and its quality. The size of cereal yield is determined by optimal crop stand density and ear productivity. These indicators are governed not only by plant biological characteristics, climate conditions, since moisture regime in the second half of the growing season plays a decisive role for grain mass, but also by nutrition conditions.

In the first experimental year, the number of productive stems of common wheat varied between 336–451 m^{-2}, spelt wheat produced 10% fewer productive stems compared with common wheat. In the second experimental year, the stand was thinner because of the cold-kill; however, tillering coefficient was higher for common wheat whose number of productive stems ranged from 108 to 198 m^{-2}, and for spelt from 150 to 204 m^{-2}. The greatest number of productive stems was produced in 2012: in the common wheat crop it varied between 574–651 m^{-2}, and in spelt crop it varied between 501–564 m^{-2}.

It is seen from Table 5 that although both winter wheat species were grown in the same type of soil, the yield significantly depended on the species grown (in 2010 – F_{fact} = 69.29**, LSD_{05} = 0.44; in 2011 – F_{fact} = 36.76**, LSD_{05} = 0.43; in 2012 – F_{fact} = 620.59**, LSD_{05} = 0.18), and organic fertilizer Ekoplant and Biokal 01 did not exert any essential influence on the yield. Averaged over all treatments grain yield for spelt in 2010 was 4.73 Mg ha^{-1}, for common wheat it was 6.53 Mg ha^{-1}; in 2011, the grain yield amounted to 3.44 Mg ha^{-1} and 2.19 Mg ha^{-1}, in 2012 – 7.52 Mg ha^{-1}, spelt – 5.26 Mg ha^{-1}, respectively (Table 5). The yield indicators obtained in 2010 were better compared with Janu auskaitė and Mašauskas' (2004) research carried out on the same soil as in this study, where wheat yield averaged 4.15 Mg ha^{-1}. In 2010, common wheat yield was by on average 28% higher than that of spelt. Having used Ekoplant fertilizer, spelt grain yield increased by 7%, and having used it in combination with Biokal 01 the yield increase amounted to 8%. In 2011, the grain yield was negatively affected by the weather conditions (Figs 1 and 2) – there was little rainfall in spring, which resulted in a shortage of moisture in the surface soil layer, because of which plants performed poorly after the cold winter and the crops thinned out. In 2011, upon resumption of vegetative growth, the soil moisture was by 1.41% lower, compared with that in 2010. However, just like in 2010, in 2011 the winter wheat yield of both species was significantly increased by the Ekoplant fertilizer applied in combination with Biokal 01. While in 2012, the common wheat grain yield was most markedly (by 4%) increased by the ecological fertilizer Ekoplant and that of spelt (by 6%) by the bio-activator Biokal 01 applied for three times at different wheat growth stages.

Our research evidenced that even in adverse years (little sunshine during wheat ripening period in July) organically grown spelt produced grain whose quality met the standards of food grain extra class (LST 1524:2003) and in terms of nutritive value it compared to other species (*Triticum durum* Desf.) (Galova, Knoblochova, 2001). Literature sources indicate that protein and gluten content in grain is closely related, since its major fractions are glutenins and gliadins (Triboi et al., 2000). The highest gluten content due to extra fertilization is accumulated in wheat grain when the number of sunshine hours is not less than 816–1002 h during wax maturity stage (Janušauskaitė, Šidlauskas, 2004). Our research indicated that in 2010, average values of protein and gluten were highest for spelt grain. They were by 25.2% and 31.3% respectively higher than those for common wheat grain (Table 6). In 2011, protein and gluten contents in all grain samples tested (spelt and common wheat) did not differ and averaged values made up 15.0–15.3% and 29.1–30.0%, respectively. This might have been influenced by the fact that due to the severe winter, the plants in a thinned out crop formed the larger half of grain yield from the secondary stems and the grains were of a poorer quality. Comparison of the three experimental years showed the percentages of protein and gluten to be the highest in 2012. This was influenced by the protracted droughty period favourable for protein synthesis before harvesting, which can be seen from the weather data provided in Figure 2. In 2012, the average values of protein and gluten for spelt were by 26.5% and 29.2%, respectively higher than those for common wheat.

Table 5. Winter wheat grain yield

Joniškėlis Experimental Station, 2010–2012

Fertilization (factor B)	Winter wheat (factor A)						Mean factor B		
	2010		2011		2012				
	T. aestivum	*T. spelta*	*T. aestivum*	*T. spelta*	*T. aestivum*	*T. spelta*	2010	2011	2012
	Yield Mg ha^{-1}								
Without fertilizer	6.53	4.53**	1.59	3.28**	7.37	5.15**	5.53	2.44	6.26
TSF	6.21*	4.54**	1.80	3.27**	7.47	5.30**	5.38	2.54	6.39
E + TSF	5.96*	4.71**	1.96	3.37**	7.64	5.24**	5.34	2.67	6.44
B01	6.21*	4.80**	2.42	3.39**	7.32	5.48**	5.51	2.91	6.40
E + B01	7.11	4.91**	2.86*	3.68**	7.62	5.06**	6.01	3.27*	6.34
E	7.15	4.87**	2.50	3.64**	7.68	5.35**	6.01	3.07	6.52
Mean factor A	6.53	4.73**	2.19	3.44**	7.52	5.26**	5.63	2.82	6.39

* – $P < 0.05$, ** – $P < 0.01$

Table 6. Winter wheat grain quality

Joniškėlis Experimental Station, 2010–2012

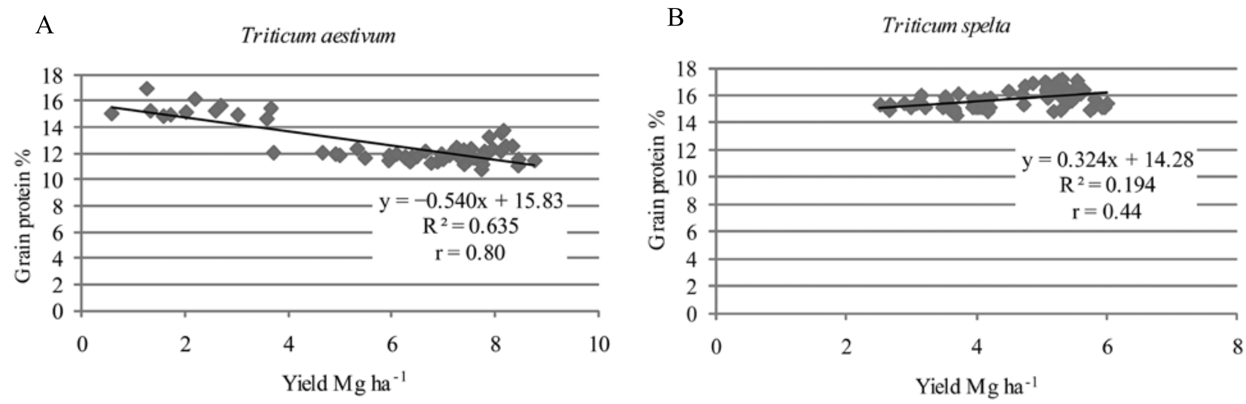
Fertilization (factor B)	Winter wheat (factor A)						Mean factor B		
	2010		2011		2012				
	T. aestivum	*T. spelta*	*T. aestivum*	*T. spelta*	*T. aestivum*	*T. spelta*	2010	2011	2012
	Grain protein %								
Without fertilizer	11.5	15.2**	15.1	15.2	11.9	16.6**	13.4	15.2	14.3
TSF	11.5	15.7**	15.0	14.9	12.0	16.5**	13.6	15.0	14.3
E + TSF	11.7	15.5**	15.5	14.9	12.0	16.4**	13.6	15.2	14.2
B01	11.7	15.7**	15.8	15.1	12.3	16.6**	13.7*	15.5	14.5
E + B01	11.5	15.6**	15.3	15.0	12.2	16.7**	13.6	15.2	14.5
E	11.7	15.3**	15.3	15.0	12.5	16.5**	13.5	15.2	14.5
Mean factor A	11.6	15.5**	15.3	15.0	12.2	16.6**	13.6	15.2	14.4
	Gluten %								
Without fertilizer	20.9	29.8**	29.2	30.2	23.5	34.7**	25.4	29.7	29.1
TSF	21.0	31.1**	29.7	29.8	23.9	34.3**	26.1	29.8	29.1
E + TSF	21.2	31.0**	30.3	29.4	23.8	33.9**	26.1	29.8	28.9
B01	21.3	31.2**	30.7	29.7	24.5	33.9**	26.3*	30.2	29.2
E + B01	21.1	30.8**	30.2	30.1	24.5	35.0**	26.0	30.2	29.8
E	21.1	30.2**	30.0	29.9	25.3*	33.8**	25.7	30.0	29.6
Mean factor A	21.1	30.7**	30.0	29.9	24.3	34.3	25.9	30.0	29.3
	Starch %								
Without fertilizer	68.2	65.1**	63.1	65.1	67.8	64.4**	66.7	64.1	66.1
TSF	68.4	65.1**	64.9	65.7*	67.8	64.4**	66.8	65.3	66.1
E + TSF	68.1	65.0**	62.3	66.0*	67.7	64.5**	66.6	64.2	66.1
B01	67.8	64.9**	62.3	65.5	67.5	64.4**	66.4	63.9	66.0
E + B01	68.5	64.8**	63.3	65.7*	67.5	64.4**	66.7	64.5	66.0
E	68.4	65.2**	63.1	66.3*	67.2*	64.3**	66.8	64.7	65.8
Mean factor A	68.2	65.0**	63.2	65.7**	67.6	64.4**	66.6	64.5	66.0

* – $P < 0.05$, ** – $P < 0.01$

There was no significant interaction among winter wheat grain quality indicators for both factors (A × B); they were discussed as separate factors. It is likely that the deterioration of grain quality indicators was caused by rainy July in 2010 and 2011 experimental years. In 2010, the rainfall rate in July was 74.4 mm and in 2011 – 95.6 mm, or it was by 7.0% and 27.6% higher, compared with the long-term mean. While in July 2012, the amount of rainfall was by 1.8 mm lower compared with the multi-year average (Figs 1 and 2). In 2010, Biokal 01 applied three times per growing season significantly increased protein and gluten content in grain, respective use of Ekoplant fertilizer and other combinations of the bio-activators revealed an insignificant trend towards increasing protein and gluten content. In similar research conducted by other researchers grain protein content was found to depend on winter wheat varietal characteristics, fertilization, and most markedly on the weather conditions (Sliesaravičius et al., 2006; Cesevičienė, Mašauskienė, 2008).

According to grain chemical composition, winter wheat is attributed to plants that accumulate carbohydrates. Starch accounts for 60–65% of wheat grain. In 2010 and 2012, grain starch content was 4.7% higher in common wheat compared with spelt, in 2011 there were no significant differences. The ecological fertilizer and bio-activators used in our trials did not increase grain starch content, which in 2010 was on average 66.6%, in 2011 – 64.5%, 2012 – 66.0%. Like the data from the separate experimental years, averaged data showed that the ecological fertilizer and bio-activators applied did not have any significant effect on starch content in grain (Table 6).

The results of the correlation-regression analysis of yield structural elements showed a negligible relationship between them. The correlation-regression analysis of common winter wheat and spelt grain yield and protein content revealed a variable relationship between these indicators. For common wheat, the correlation coefficient between grain yield and protein content was relatively high (r = 0.80, p < 0.01) (Fig. 3A). It is seen from Figure 3A that with increasing grain yield, protein content in grain consistently declined, i.e. an increase in winter wheat grain yield of 1 t ha^{-1} gave a 0.4% reduction of grain protein content.



Joniškėlis Experimental Station, 2010–2012

Figure 3. The relationship between grain protein content and grain yield of common and spelt winter wheat in 2010–2012 growing season

However, for spelt there was no relationship between grain protein content and grain yield (Fig. 3B). This analysis proved grain protein content to be a strong, rather stable genetic trait for spelt, which has also been indicated by other researchers (Le Bail, Meynard, 2003).

Conclusions

1. The field experiments showed that on average over all research treatments the spelt cv. 'Franckenkorn' produced significantly longer ears in all experimental years compared with the common wheat cv. 'Toras'. However, the grain mass per ear of the common wheat was higher, except in 2011, when the thinned out crop due to unfavourable winter formed a larger half of yield from the secondary stems.

2. Despite the adverse weather conditions in 2011, like in 2010 and 2012, fertilization with ecological fertilizer Ekoplant and its use in combination with the bio-activators Terra Sorb Foliar and Biokal 01 resulted in an improvement of secondary parameters of winter wheat productivity – ear length, grain number per ear and grain mass; the use of only Biokal 01 or Terra Sorb Foliar once or three times per growing season did not have any significant effect.

3. In separate experimental years, the weather conditions played an important role in shaping wheat grain yield and for the efficiency of fertilizer and bio-activators. In 2010 and 2012, averaged over all fertilization treatments, common wheat produced 27.6% and 30.1% respectively higher grain yield than spelt, while in 2011, due to the poorer overwinter survival of common wheat, which was evidenced by the data of grain mass per ear, the yield difference was not significant. In 2010 and 2011, the highest yield increase for both wheat species was observed when Ekoplant fertilizer had been used in combination with the bio-activator Biokal 01, while in 2012 – when Ekoplant fertilizer had been used.

4. The main grain quality indicators – average values of protein and gluten in 2010 and 2012 were by 25.2% and 31.3% and 26.5 and 29.2% respectively higher for spelt compared with common wheat, while in 2011 there were no significant differences between them. This resulted from the fact that after a severe winter the thinned out crop formed a larger half of yield from the secondary stems and the grains were of a poorer quality.

5. The correlation-regression analysis showed that for common wheat the application of the ecological fertilizer Ekoplant and bio-activators Biokal 01 and Terra Sorb Foliar resulted in an increase in grain yield and a reduction in protein and gluten concentration; while for spelt wheat, whose high grain gluten content is a genetic characteristic, with increasing yield, grain quality indicators remained stable.

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Paprastojo (*Triticum aestivum* L.) bei spelta (*Triticum spelta* L.) kviečių produktyvumo ir kokybės įvertinimas priklausomai nuo tręšimo

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Santrauka

Lietuvos agrarinių ir miškų mokslų centro Joniškėlio bandymų stotyje 2009–2012 m. ekologinėje agrosistemoje tirta ekologinių trąšų Ekoplant ir bioaktyvatorių Biokal 01 bei Terra Sorb Foliar įtaka spelta žieminio kviečio (*Triticum spelta* L.) veislės 'Franckenkorn' ir paprastojo žieminio kviečio (*Triticum aestivum* L.) veislės 'Toras' produktyvumo elementų formavimuisi, grūdų derliui bei kokybei. Dirvožemis – giliau karbonatingas giliau glėjiškas sunkaus priemolio rudžemis (RDg4-k2). Įvairiais tyrimų metais meteorologinės, ypač žieminių kviečių žiemojimo, sąlygos labai skyrėsi, o tai lėmė nevienodą įtaką skirtingų rūšių kviečių derliui ir kartu trąšų efektyvumui. Pirmaisiais ir trečiaisiais (2010 ir 2012) tyrimų metais žieminiai kviečiai peržiemojo gerai, paprastųjų kviečių grūdų derlius buvo 27,6 ir 30,1 % didesnis nei spelta kviečių. Antraisiais (2011) tyrimų metais dėl nepastovios žiemos sausio mėnesį atšilus, po to oro temperatūrai staiga nukritus iki −25° C, labiau išretėjo paprastieji nei spelta kviečiai ir visuose tręšimo variantuose jų derlius buvo gerokai mažesnis. 2010–2011 m., panaudojus ekologines trąšas Ekoplant ir jų derinius su bioaktyvatoriais Biokal 01 bei Terra Sorb Foliar, kviečių biometriniai rodikliai padidėjo, t. y. stiebo masė, varpos ilgis ir masė, grūdų skaičius varpoje esmingai padidėjo panaudojus trąšas Ekoplant ir derinį su Terra Sorb Foliar. 2012 m. biometrinių rodiklių padidėjimui didžiausią įtaką turėjo bioaktyvatorius Biokal 01. Didžiausias abiejų rūšių kviečių grūdų derliaus priedas 2010–2011 m. buvo trąšas Ekoplant panaudojus kartu su bioaktyvatoriumi Biokal 01, o 2012 m. – trąšas Ekoplant. Trąšos Ekoplant ir jų derinys su bioaktyvatoriais Terra Sorb Foliar bei Biokal 01 kviečių grūdų kokybiniams rodikliams esminės įtakos neturėjo, tačiau naudojant bioaktyvatorių Biokal 01 baltymų ir glitimo kiekis 2010 m. padidėjo atitinkamai 2,2 ir 3,4 %.

Reikšminiai žodžiai: bioaktyvatoriai, derlius, ekologinės trąšos, kokybė, paprastieji ir spelta kviečiai, produktyvumo elementai.