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Effect of algae *Ecklonia maxima* extract (Kelpak SL) on yields of common wheat, durum wheat and spelt wheat

Wpływ ekstraktu z alg *Ecklonia maxima* (Kelpak SL) na plonowanie pszenicy zwyczajnej, pszenicy twardej i pszenicy orkisz

Summary. The 3-year experiment was concerned with the response of spring forms of common wheat (*Triticum aestivum* L. subsp. *aestivum*), durum wheat (*Triticum durum* Desf.) and spelt wheat (*Triticum aestivum* subsp. *spelta* L. em. Thell.) to the foliar application of a plant growth stimulant (extract from marine algae *Ecklonia maxima*), with the commercial name of Kelpak SL (GS), as compared to control treatment (C). The following parameters were analysed: yield of grain, yield components (number of ears, weight of 1000 kernels, number and weight of kernels per ear) and physical indicators of grain quality (test weight, uniformity and vitreosity of grain). The study showed that the level of yielding and the yield components were related primarily with the wheat genotype, but they depended also on the agro-climatic conditions and on the algae extract and control experimental treatments. The application of algae extract, compared to the control, caused a significant increase in the yields of the spring wheat species under study, on average by 7.0%. Canopy spraying with algae extract had a favourable effect on the number of ears, on he number and weight of kernels per ear, but it had no effect on the weight of 1000 kernels. The grain quality of durum wheat, spelt wheat and common wheat was affected more strongly by the weather conditions in the successive years of the study and by the genotype than by the foliar application of algae extract. The spelt genotypes were characterised by lower yields and lower grain quality than common wheat and the durum wheat genotypes.

Key words: common wheat, durum wheat, spelt wheat, grain quality, grain yield, algae extract

INTRODUCTION

Implementation of sustainable agriculture requires the application of plant production systems that integrate, among other things, reduced risk involved in the application of chemical plant protection agents and increased biodiversity, and at the same time are adapted to the current climate change. As indicated by Chbani et al. [2013], modern agriculture expects the researchers to seek new biotechnological solutions that, in spite of limitation of the use of chemicals, would permit satisfactory levels of crop yields. One of such solutions could be the application of extracts from marine algae. Those organic substrates contain, among other things, microelements [Zodape 2001, Muhammad et al. 2013], but first of all they are a source of natural regulators of plant growth [Mooney and van Staden 1986, Zodape et al. 2009]. Although commercial extracts can be produced with various methods and from various species of algae (mainly brown algae), their biological activity is often similar [Stirk and van Staden 1997]. Whereas, their effectiveness is closely related with the concentration of the extract, as only the correct concentration can ensure positive effects [Mooney and van Staden 1985, Kumar and Sahoo 2011]. Literature reports indicate that such extracts have positive effects on, among other things, plant tolerance to abiotic stresses [Mooney and van Staden 1985, Beckett and van Staden 1989, 1990, Craigie 2011] and on plant growth and level of yielding [Khan et al. 2009, Kumar and Sahoo 2011, Shah et al. 2013]. However, the strength of response of plants to the application of algae extract may differ with relation to the species and even to the cultivar [Reitz and Trumble 1996].

Within the genus *Triticum* the species that is the most frequently grown in the world is the hexaploid common wheat, used primarily as raw material for the production of bread [Bushuk 1998]. Also a notable economic importance is attributed to the tetraploid durum wheat which, due to its high grain quality, is used mainly for the production of such food products as pasta, couscous and bulgur [Korkut et al. 2007], and in a variety of local kinds of bread [Troccoli et al. 2000]. Also the hexaploid spelt wheat evokes a growing interest among the producers and the consumers, as although it is a sub-species of common wheat, it surpasses it in terms of nutritional and health-promoting values [Rachoń and Szumiło 2009]. Spelt wheat is used most often for the production of wholemeal food products such as bread and pasta [Kohajdová and Karovicová 2008].

Not much information is available on the application of growth stimulants obtained from marine algae and their effect on the yield, yield components and physical parameters of wheat grain. For this reason the study presented here was an attempt at estimation of the effect of the growth stimulant, with the commercial name of Kelpak SL, on the above parameters of common, durum and spelt wheat. The research hypothesis assumed that the level of yields and grain quality of spring forms of common wheat, durum wheat and spelt wheat are determined genetically, but they are also affected by the application of extract from marine algae *Ecklonia maxima*.

MATERIALS AND METHODS

The field experiment was conducted during the period from 2010 to 2012 at the Experimental Farm Felin (51°22'N, 22°64'E) of the University of Life Sciences in Lublin, south-eastern Poland. The experiment was set up in the randomised blocks system, with 4 replicates, and the area of the experimental plots was 22 m^2. The experiment comprised the following factors: I. genotypes (cultivars and breeding line) of spring wheat (G): 1) cv. Parabola (common wheat – *Triticum aestivum* L. subsp. *aestivum*), 2) cv. Kharkivska 39 (durum wheat – *Triticum durum* Desf.), 3) LGR 626b/99/4 (durum wheat), 4) cv. Blauer Samtiger (spelt wheat – *Triticum aestivum* subsp. *spelta* L. em. Thell.), 5) cv. Spelz aus Tzari Brod (spelt wheat), and II. treatments (T): 1) control (C), and plant growth stimulant with the commercial name of Kelpak SL (GS).

After the forecrop harvest (winter rapeseed) the set of post-harvest tillage was performed, as well as fertilisation with phosphorus (31 kg $P \cdot ha^{-1}$) and potassium (100 kg $K \cdot ha^{-1}$), and in autumn ploughing to the depth of 25–30 cm was made. In spring harrowing was applied, a single dose of nitrogen (30 kg $N \cdot ha^{-1}$), and the soil was prepared for sowing by means of a cultivation set. In all the treatments two more doses of nitrogen were applied as topdressing in the phase of shooting (20 kg $N \cdot ha^{-1}$), and as foliar application in the phase of heading (20 kg $N \cdot ha^{-1}$). All the cultivars and the line of wheat were sown in the 2nd decade of April, in the amount of 500 kernels per m^2. For the purpose of prophylactic protection of the plants against fungal diseases the sowing material was primed with the fungicide Baytan Universal 094 FS (400 cm^3 of fungicide with 200 cm^3 of water per 100 kg of grain).

The plant growth stimulant Kelpak (active ingredients – natural plant hormones: auxins – 11.0 mg in dm^3 and cytokinins – 0.031 mg in dm^3), produced from marine algae *Ecklonia maxima* [Khan et al. 2009], was applied once, as foliar application, in the dose of 1.5 $dm^3 \cdot ha^{-1}$, in the form of water solution (300 $dm^3 \cdot ha^{-1}$), in phase 14–15 BBCH scale. In the years of the study, the treatment of spraying with extract from marine algae, Kelpak SL, was conducted at air temperatures in the range of 10−15°C and relative air humidity in the range of 50−65%. In the phase of tillering, to reduce weed infestation, all the treatments were sprayed with herbicides Attribut 70 WG (60 $g \cdot ha^{-1}$) and Sekator 125 OD (100 $cm^3 \cdot ha^{-1}$). In addition, a liquid potassium-magnesium-sodium fertiliser with an admixture of copper (PRP EBV) was applied as foliar feeding, at the dose of 2 $dm^3 \cdot ha^{-1}$, in the tillering phase. No fungicide or insecticide protection was applied.

Information concerning the agro-climatic conditions during the period of vegetation of spring wheat in the years of the experiment is presented in Table 1. The year 2011 appeared to be the most favourable for wheat growth in terms of the sum of precipitations and mean air temperature.

The experimental field was situated on a grey-brown podzolic soil developed from loess formations, with the particle size distribution of loamy silts, classified in the agronomic weight category of medium soils. The soil is characterised by a high content of available phosphorus (7.63 mg $P \cdot 100\ g^{-1}$), medium of potassium (11.87 mg $K \cdot 100\ g^{-1}$), high of magnesium (5.55 mg $Mg \cdot 100\ g^{-1}$), and has a slightly acidic reaction of pH_{KCl} 6.3.

The following parameters were determined: number of ears per 1 m^2, grain yield ($t \cdot ha^{-1}$), number of kernels per ear, weight of kernels per ear, weight of 1000 kernels (g, TKW), test weight ($kg \cdot hL^{-1}$), grain uniformity (%) and grain vitreosity (%), in conformance with the relevant standards [Szumiło and Rachoń 2009].

The results were processed statistically with the analysis of variance (ARSTAT). The significance of differences between mean values was determined with Tukey's HSD (Honest Significant Difference) test at significance level of 5% ($p < 0.05$).

RESULTS

The results concerning the effect of the plant growth stimulant Kelapk (GS), as compared to the control treatments (C), on the yielding of all species of the wheat included in the research are presented in Table 2. The application of the GS caused a significant increase of yields irrespective of the wheat genotype.

A positive effect of GS on the level of yields appeared in the case of most of the wheat genotypes, but their response to the stimulant was varied. Compared to C, the application of GS caused an increase of yields of the durum wheat breeding line LGR 626b/99/4 by an average of 9.9%, and of the spelt wheat cultivar Blauer Samtiger by an average of 9.5%. A somewhat weaker response to the application of the GS was noted in the case of cv. Kharkivska 39 (durum wheat) and cv. Parabola (common wheat). Whereas, cv. Spelz aus Tzari Brod (spelt wheat) was characterised the smallest and statistically insignificant increase of yield, by an average of 4.4%.

The weather conditions during the three-year cycle of the study had an effect on the yields of studied species of spring wheat. In 2011 the average yield of wheat was significantly higher than in the other years of the study. Compared to C, the application of GS stimulated an increase of yields both under conditions of rainfall deficit during the vegetation (year 2012), and under conditions of non-uniform occurrence of rainfalls (2011). In vegetation season characterised by a considerable excess of rainfall (2010) relative to the long-term norm (1951–2010), the application of GS did not result in the expected increase of yields (Table 1).

Irrespective of treatments T, among the wheats under study the highest yields were obtained in the case of common wheat. Average for the three-year period of the study, the yield of durum wheat genotypes was at the level of 84.2% (Kharkivska 39) and 76,4% (LGR 626b/99/4) of the yield of common wheat, while the lowest yields were characteristic of the spelt wheat genotypes.

The increase of yield caused by the application of GS resulted primarily from a significant increase of the number of ears per area unit (Table 2). That tendency related to all of the wheat genotypes analysed, but it was statistically insignificant.

Table 1. Agro-climatic conditions at the Felin Experimental Station

Years	Months					Total average
	April	May	June	July	August	
Monthly total precipitation (mm)						
2010	24.5	156.7	65.6	101.0	132.8	480.6
2011	29.9	42.2	67.8	189.0	65.3	394.2
2012	34.0	56.3	62.8	52.3	37.6	243.0
LYM[1]	39.0	60.7	65.9	82.0	70.7	318.3
Monthly average temperature (°C)						
2010	9.4	14.4	18.0	21.6	20.6	16.8
2011	10.3	14.2	18.6	18.4	18.8	16.1
2012	9.5	15.0	17.3	21.4	19.2	16.5
LYM[1]	7.4	13.0	16.3	18.0	17.2	14.4

[1] LYM = long years mean 1951–2010.

Table 2. Influence of growth stimulant on grain yield and number of ears of wheat

Variable	Grain yield ($t \cdot ha^{-1}$)			Number of ears per 1 m^2		
	treatment (T)		mean (Y)	treatment (T)		mean (Y)
Years (Y)	C	GS		C	GS	
2010	4.37n	4.42n	4.40B	373n	380n	376B
2011	4.27b	4.75a	4.51A	393b	426a	410A
2012	4.17b	4.61a	4.39B	330b	353a	341C
Genotypes (G)			mean (G)			mean (G)
Parabola (ta)	5.46b	5.80a	5.63A	401n	421n	411A
Kharkivska 39 (td)	4.58b	4.90a	4.74B	326n	354n	340C
LGR 626b/99/4 (td)	4.08b	4.53a	4.30C	308n	336n	322D
Blauer Samtiger (ts)	3.52b	3.89a	3.70D	409n	431n	420A
Spelz aus Tzari Brod (ts)	3.72n	3.84n	3.78D	382n	388n	385B
Mean (T)	4.27b	4.59a	–	365b	386a	–

C = control; GS = growth stimulant; n = not significant; (ta) = common wheat; (td) = durum wheat; (ts) = spelt wheat. Values with different lowercase letter in the same line indicate significant differences among treatment (T). Means with different uppercase letter in a column indicate significant differences accordingly among years (Y) and among genotypes (G). Significant level was set at $p < 0.05$ (Tukey's HSD test).

Table 3. Influence of growth stimulant on TKW and number of kernels per ear of wheat

Variable	TKW (g)			Number of kernels per ear		
	treatment (T)		mean (Y)	treatment (T)		mean (Y)
Years (Y)	C	GS		C	GS	
2010	37.1n	36.8n	36.9C	32.5n	32.8n	32.7B
2011	44.1n	44.0n	44.1A	24.9n	25.5n	25.2C
2012	39.5n	39.8n	39.6B	33.2n	34.0n	33.6A
Genotypes (G)			mean (G)			mean (G)
Parabola (ta)	41.7n	41.7n	41.7B	33.9n	34.1n	34.0A
Kharkivska 39 (td)	43.9n	43.6n	43.8A	32.8n	33.0n	32.9B
LGR 626b/99/4 (td)	39.8n	39.7n	39.7C	34.2n	34.7n	34.5A
Blauer Samtiger (ts)	36.8n	37.1n	36.9E	24.6n	25.6n	25.1D
Spelz aus Tzari Brod (ts)	38.9n	38.9n	38.9D	25.6n	26.5n	26.0C
Mean (T)	40.2n	40.2n	–	30.2b	30.8a	–

C = control; GS = growth stimulant; n = not significant; (ta) = common wheat; (td) = durum wheat; (ts) = spelt wheat. Values with different lowercase letter in the same line indicate significant differences among treatment (T). Means with different uppercase letter in a column indicate significant differences accordingly among years (Y) and among genotypes (G). Significant level was set at $p < 0.05$ (Tukey's HSD test).

In the years 2011 and 2012 the spraying with GS, compared to C, stimulated an increase of the numbers of ears per area unit. Irrespective of the experimental factors, the highest numbers of ears were obtained in 2011, and the lowest in 2012.

The durum wheat genotypes, especially line LGR 626b/99/4, formed significantly lower number of ears than the common wheat and the spelt wheat genotypes.

Table 4. Influence of growth stimulant on weight of kernels per ear and test weight of wheat

Variable	Weight of kernels per ear (g)			Test weight (kg·hL^{-1})		
	treatment (T)		mean (Y)	treatment (T)		mean (Y)
Years (Y)	C	GS		C	GS	
2010	1.224n	1.223n	1.224B	67.7a	66.8b	67.3C
2011	1.097n	1.124n	1.110C	68.4n	68.2n	68.3B
2012	1.297n	1.334n	1.316A	71.2n	71.2n	71.2A
Genotypes (G)			mean (G)			mean (G)
Parabola (ta)	1.382n	1.401n	1.391B	71.0n	71.3n	71.2B
Kharkivska 39 (td)	1.435n	1.432n	1.434A	72.4n	71.7n	72.0A
LGR 626b/99/4 (td)	1.341n	1.353n	1.347C	70.0n	69.3n	69.7C
Blauer Samtiger (ts)	0.878n	0.919n	0.899E	65.3n	64.9n	65.1E
Spelz aus Tzari Brod (ts)	0.995n	1.030n	1.012D	66.9n	66.5n	66.7D
Mean (T)	1.206b	1.227a	–	69.1a	68.7b	–

C = control; GS = growth stimulant; n = not significant; (ta) = common wheat; (td) = durum wheat; (ts) = spelt wheat. Values with different lowercase letter in the same line indicate significant differences among treatment (T). Means with different uppercase letter in a column indicate significant differences accordingly among years (Y) and among genotypes (G). Significant level was set at $p < 0.05$ (Tukey's HSD test).

Table 5. Influence of growth stimulant on grain uniformity and grain vitreosity of wheat

Variable	Grain uniformity (%)			Grain vitreosity (%)		
	treatment (T)		mean (Y)	treatment (T)		mean (Y)
Years (Y)	C	GS		C	GS	
2010	78.3n	76.9n	77.6C	45.5n	46.7n	46.1A
2011	86.0n	85.3n	85.7A	29.5n	28.6n	29.0B
2012	81.6b	86.5a	84.1B	44.5b	47.7a	46.1A
Genotypes (G)			mean (G)			mean (G)
Parabola (ta)	86.4n	87.3n	86.8B	45.3n	45.1n	45.2C
Kharkivska 39 (td)	92.8n	92.5n	92.7A	63.5n	63.6n	63.5B
LGR 626b/99/4 (td)	87.9n	87.4n	87.6B	68.3n	68.4n	68.4A
Blauer Samtiger (ts)	65.1n	66.4n	65.8D	9.6b	12.6a	11.1E
Spelz aus Tzari Brod (ts)	77.8b	80.9a	79.4C	12.3b	15.1a	13.7D
Mean (T)	82.0b	82.9a	–	39.8b	41.0a	–

C = control; GS = growth stimulant; n = not significant; (ta) = common wheat; (td) = durum wheat; (ts) = spelt wheat. Values with different lowercase letter in the same line indicate significant differences among treatment (T). Means with different uppercase letter in a column indicate significant differences accordingly among years (Y) and among genotypes (G). Significant level was set at $p < 0.05$ (Tukey's HSD test).

Canopy spraying with GS, compared to C, stimulated a slight but statistically significant increase of the number and weight of kernels per ear, but it did not differentiate the weight of 1000 kernels (Table 3, Table 4).

The varying weather conditions during the particular vegetation seasons had a significant effect on the values of the grain yield components. Irrespective of the experimental factors, in 2010 the lowest weight of 1000 kernels was obtained. The highest TKW, and the smallest number and weight of kernels per ear, were formed by the wheats in 2011. Whereas, year 2012 proved to be the most favourable for the formation of a high number and weight of kernels per ear.

The spelt wheat genotypes, especially cv. Blauer Samtiger, were characterised by a lower weight of 1000 kernels, and number and weight of kernels per ear, compared to the common wheat and the durum wheat genotypes.

Contrary to expectation the use of GS, compared to the control, did not have a big positive effect on grain quality of all the genotypes of wheat (Table 4, Table 5).

There was only an increase of uniformity of grain of the spelt wheat cultivar Spelz aus Tzari Brod, and an increase of vitreosity of grain of both spelt wheat genotypes. Irrespective of the genotype, the application of GS caused an increase of grain uniformity and vitreosity, especially in 2012, and a decrease of test weight, especially in 2010.

Grain quality of the wheat genotypes depended significantly on the weather conditions. The highest test weight of wheat grain was noted in 2012, and the lowest values of test weight and grain uniformity were observed in 2010. In 2011 the wheats form grain characterized with the highest level of uniformity, but lowest vitreosity.

Irrespective of treatments T, the spelt wheat genotypes were characterised by the lowest test weight, uniformity and vitreosity of the grain, while the durum wheat genotypes were characterised by the highest grain vitreosity.

DISCUSSION

Compared to the control, the application of GS caused a significant increase of grain yields of most of the studied cultivars. Nevertheless, the variation of yields between the particular genotypes indicates that it is determined by the genetic factor. Mooney, and van Staden [1985] also noted a significant increase of yields of wheat as a result of application on an extract from algae *Ecklonia maxima*, with the name of Kelpak 66. In other studies a significant increase of yields was observed also in relation to wheat after the application of an extract from *Kappaphycus alvarezii* [Zodape et al. 2009, Shah et al. 2013], and an extract from *Sargassum wightii* [Kumar and Sahoo 2011]. However, in general plants display a weaker response to algal extracts under conditions close to the optimum [Beckett and van Staden 1989, 1990, Craigie 2011]. In the study presented in the paper, the application of GS did not cause any significant increase in the level of yields only in the vegetation season characterised by a notable excess of rainfall and high air temperature. The weaker-than-expected effect of the GS on plants during that period could have been a result of intensified appearance of pathogenic fungi.

Analysis of yield components revealed that the increase of wheat grain yields caused by the application of the GS was related mainly with increased number of ears. Similar results were presented also by Zodape et al. [2009] and Shah et al. [2013], demonstrating at the same time a significant increase of the weight of kernels. In our study no effect of the GS on the weight of 1000 kernels was observed, while a favourable effect of the application of the GS on the number and weight of kernels per ear was noted. An increase in the number of kernels as a result of application of an algal extract was also demonstrated in other studies [Beckett and van Staden 1989, Kumar and Sahoo 2011].

The quality of wheat is defined as its suitability for a specific type of use, and the quality of a ready product is correlated with the physical and chemical properties of the raw material [Yildirim et al. 2013]. One of the parameters determining the milling value of grain is its test weight [Troccoli et al. 2000]. In this study, the effect of treatments T on the values of the physical indicators of grain quality was small, but statistically significant. The foliar application of GS had a negative effect on test weight of the grain irrespective of the wheat genotype, while a positive response was noted in the case of grain uniformity of one of the spelt wheat cultivars (Spelz aus Tzari Brod). All the wheat genotypes were characterised by relatively low grain test weight. On the other hand, grain uniformity, especially in the case of the common wheat and the durum wheat genotypes, was at a satisfactory level.

Literature reports indicate that high quality wheat grain, especially durum wheat, should be characterised by vitreosity, i.e. its parenchyma should be semi-transparent, with glassy structure [Bushuk 1998, Korkut et al. 2007]. In this study, the foliar application of the GS, relatively to the control, did not differentiate the grain of common wheat and of the durum wheat genotypes. The percentage vitreosity of grain of durum wheat genotypes grown under the conditions of south-eastern Poland was at an average level and it was somewhat lower than in other regions [Korkut et al. 2007, Yildirim et al. 2013]. In the opinion of Korkut et al. [2007], the level of grain yields and grain vitreosity are mutually correlated. The study presented here clearly indicates that in a season characterised by weather conditions conducive to high yields the lowest percentage of vitreous grains was obtained.

CONCLUSIONS

1. Level of yields and the yield components was related primarily with the wheat genotype, but it also depended on the agro-climatic conditions and on the treatments factor.
2. The application of algae extract, compared to control, caused a significant increase of yields of the analyzed wheat species, on average by 7.0%.
3. The spraying of the canopy with the algae extract had a favourable effect on the number of ears, and on the number and weight of kernels per ear, but it did not affect the weight of 1000 kernels.
4. The weather conditions in the successive years, and the genetic factor, had a greater effect on the quality of grain of durum, spelt and common wheat than the application of algae extract.
5. The spelt wheat genotypes were characterised by a lower level of yields and lower grain quality than the common wheat and the durum wheat genotypes.

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Streszczenie. Przeprowadzone 3-letnie badanie dotyczyło reakcji jarych form pszenicy zwyczajnej (*Triticum aestivum* L. subsp. *aestivum*), pszenicy twardej (*Triticum durum* Desf.) i pszenicy orkisz (*Triticum aestivum* subsp. *spelta* L. em. Thell.) na dolistne zastosowanie stymulanta wzrostu roślin (ekstrakt z alg morskich *Ecklonia maxima*) o nazwie handlowej Kelpak SL (GS). Analizie poddano następujące parametry: plon ziarna, komponenty plonu (liczba kłosów, masa 1000 ziarn, liczba i masa ziarn z kłosa) i fizyczne wskaźniki jakości ziarna (gęstość ziarna w stanie zsypnym, wyrównanie i szklistość ziarna). Z badania wynika, że poziom plonowania i komponentów plonu związany był przede wszystkim z genotypem pszenicy, jednak zależał również od warunków agroklimatycznych, a także od kombinacji obiektów opryskiwanych ekstraktem z alg i kontrolnych. Zastosowanie ekstraktu z alg w porównaniu z kontrolą spowodowało istotne zwiększenie plonu analizowanych gatunków pszenicy jarej, średnio o 7,0%. Oprysk łanu ekstraktem z alg korzystnie oddziaływał na liczbę kłosów, liczbę i masę ziarn z kłosa, natomiast nie miał wpływu na masę 1000 ziarn pszenicy. Na jakość ziarna pszenicy twardej, orkisz i zwyczajnej większy wpływ miały warunki pogodowe w kolejnych latach oraz genotyp niż dolistne zastosowanie ekstraktu z alg. Genotypy pszenicy orkisz cechowały się niższym poziomem plonowania i niższą jakością ziarna niż pszenica zwyczajna i genotypy pszenicy twardej.

Słowa kluczowe: pszenica zwyczajna, pszenica twarda, pszenica orkisz, jakość ziarna, plon ziarna, ekstrakt z alg

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