The content of *Fusarium* mycotoxins, grain yield and quality of winter wheat cultivars under organic and conventional cropping systems

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ABSTRACT

Nine cultivars of winter wheat were compared in organic and conventional crop rotation systems. Bread-making quality was evaluated using three parameters [thousand-kernel weight (TKW) in g, volume weight in g/l, protein content in %]. Grain yield, TKW and protein content of winter wheat in organic cropping system were significantly lower as compared to any intensity in conventional cropping system. However, clover as a preceding crop to winter wheat in organic crop rotation ensured a sufficient amount of nitrogen for grain yield, which was 6.72 t/ha on average of the three years. The requirement of the Czech national standard for bread wheat minimum value of protein content (11.5%) was met in conventional crop rotation in all cases. Average value of protein content in organic crop rotation met this limit too, but it was below the required value in two cases. The required value (760 g/l) of volume weight was met in majority of cases in organic crop rotation. The following species of the genus *Fusarium* were found: *F. culmorum, F. graminearum, F. poae* and *F. avenaceum*. All samples were screened for the content of deoxynivalenol (DON). There was no significant difference in the DON content between winter wheat grain from organic crop rotation and conventional crop rotation at high intensity.

Keywords: winter wheat; deoxynivalenol; organic crop rotation; conventional crop rotation; yield; quality parameters

The quality of winter wheat is determined by many factors including grain protein content, grain volume weight, thousand-kernel weight (TKW) and milling and baking characteristics. Another significant criterion of winter wheat quality is now health safety. Food safety issues due to mycotoxins of *Fusarium* infections can be very important for cereal market and food and feed chain. All these quality traits can be influenced by the environment, genotype, crop rotation and management practices.

Fusarium spp. inoculum comes from debris of host plants. Maize and wheat residues are the primary sources of infection (Krebs et al. 2000). Infected residues can release *Fusarium* ascospores for up to three years (Khonga and Sutton 1988). *Gibberella zeae* survives in residues for a long term as mycelium or chlamydospores (Nyvall 1970). However, the cultivars and environmental factors influence the growth, survival, dissemination, the incidence of *Fusarium* fungi and the disease severity (Koch et al. 2006, Klem et al. 2007) in different crop management practices.

In the Czech Republic, Fusarium head blight of wheat (FHB) is caused predominantly by *Fusarium graminearum* and *F. culmorum* (Váňová et al. 2004). The increased intensity of this disease over the last years has been attributed to the widespread adoption of minimum tillage and crop rotations with many host crops. Tillage and crop rotation with broad scale of crops are management strategies often recommended to reduce residue-borne inoculum density and pathogen survival. The disease intensity is generally greater when wheat follows host crops such as maize or wheat than in the case of wheat that follows nonhost crops such as clover, oilseed rape, or soybean in cropping sequence. These strategies may be sometimes ineffective for particular field because of the ingress of spores from external sources. Many researches suggest

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that high concentration of fungus spores can be under conditions with high inoculum density.

The spores are disseminated by wind under favourable weather conditions to wheat spikes at flowering time (Mauler-Machnik and Suty 1997). The level of mycotoxins depends on the weather course in the given year and on preceding crop rather than on cultivar resistance.

Presently the wheat cultivars require higher levels of inputs for high yield and good quality, which leads to both higher production costs and a greater risk of environmental pollution. Increasing public awareness of the latter, along with growing consumers' demand for healthier products, has led not only to greater criticism being leveled at this type of production model but also to increased emphasis on crop grown under integrated-management and organic systems (Guarda et al. 2004). The organic approach, which largely reprises the techniques in use before the introduction of mineral fertilizers and chemical weed and disease control treatments, appears to be based on the assumption that a return to such farming methods can ensure products that are both healthier and of higher quality than the standard production grown under today intensive and integrated agricultural systems.

The synthetic chemicals are not allowed in organic farming and for many diseases alternative methods of protection have been found because the effect of some diseases on milling and baking quality can have large economic impact (Everts et al. 2001). Organic disease management strategies should, from principle, be largely preventive and depend on the whole system approach, with maintenance of soil health, a central component of any strategy (Davies et al. 2002). In the case of *Fusarium* in ears, it is possible to use some more resistant cultivars or such crop management practices that make lower inoculum sources. The experience from the 1990s in mid-West of the USA with little or no rotation and with minimum tillage to reduce soil erosion are very admonish of build-up of massive amounts of soil inoculum (McMullen et al. 1997). The length of the rotation can be the key factor in determining pathogen persistence. Many pathogens (*Gaeumannomyces graminis, Pseudocercosporella herpotrichoides, Fusarium* spp.) survive in soil or on crop residues and there is a limit to how long they can survive in the absence of their hosts. The soil fertility and soil health are basic elements of organic cropping systems. A break of two to four years is sufficient to reduce inoculum to a level that will allow the production of a healthy crop (Wolf 2002). Along with food issues due to mycotoxins, effects of *Fusarium* infections on wheat quality can be disastrous. Some of the FHB mycotoxins, such as DON, present in infected wheat may be lost during the process of cleaning. The level of DON mycotoxin can differ considerably in food products and in raw material (Lancová et al. 2008).

The objective of this study was to determine the relative importance of preceding crop, adjacent crop and composition of crop rotation in the organic cropping system according to the IFOAM as compared with conventional crop management practices in favour of using fungicides, from viewpoint of grain yield and quality, and health safety evaluated on the basis of DON content in grain.

MATERIAL AND METHODS

Field trials. Field trials were laid down in plots of the Agricultural Research Institute Kroměříž, Ltd., in 2004–2006 (235 m above sea level, average annual temperature of 8.7°C and annual precipitation sum of 599 mm). Field plots of 10 m^2 area are in 4 replicates.

Organic cropping system. The 8-course crop rotation according to the IFOAM (without maize and 50% of cereals as the maximum, where winter wheat was included once) was used to study grain yield, selected quality parameters, *Fusarium* spp. in ears and trichothecene mycotoxins in grain, of which DON was assessed for winter wheat after the clover as preceding crop. The crop rotation was established in 1991 following a 2-year transient period. The area of individual plots of the crop rotation was 1 100 m^2. All post-harvest residues were dissipated and ploughed in the soil.

Crop rotation: (1) red clover, (2) winter wheat, (3) sugar beet, (4) spring barley, (5) sunflower (since 2005, poppy till 2003), (6) hulless oat, (7) pea, (8) spring wheat.

Conventional cropping system. The same parameters were examined in the 4-course crop rotation that comprised also 50% of cereals and no maize.

Crop rotation: (1) sugar beet, (2) spring barley, (3) oilseed rape, (4) winter wheat.

In this crop rotation, winter wheat was grown under the three crop management systems – intensities (L – low input, M – medium input, H – high input) following the preceding crop oilseed rape. The main differences among crop management systems were in nitrogen nutrition. The nitrogen rates at L, M and H intensity were 90, 120 and

220 kg/ha, respectively, and were applied three times during the vegetative period: first at the time of spring regeneration, second at the end of tillering, third at the stage of flag leaf visible.

Another difference was in fungicidal treatments:

Fungicide	GS 32	GS 39	GS 59
L		Bumper 25 EC 0.5 l/ha	
M	Topsin 0.5 l/ha	Artea 330 EC 0.5 l/ha	
H	Alert + Capitan 0.8 + 0.4 l/ha	Sfera 267.5 EC + Bravo 0.4 + 1 l	Amistar + Caramba 0.4 + 0.8 l/ha

and in treatments with growth regulators: L – Retacel 1 l/ha; M – Retacel 1.5 l/ha; H – Retacel + Modus 1.5 + 0.15 l/ha

Nine cultivars with different baking parameters of winter wheat were compared in both experiments: class E – Ludwig, Sulamit; class A – Batis, Bill, Complet, Ebi; class B – Drifter; class C – Contra, Estika.

The distance between the experiments was 500 m. Weeds were controlled according to the methods valid for plant protection and depending on their presence in plots each year. No treatment was done against FHB at L and M intensity.

At H intensity fungicide Caramba with a.i. metconazole was used. The plots were not artificially inoculated with spores of *Fusarium* spp.

Table 1 shows the results of agrochemical soil analyses before sowing, including the content of available nutrients in the depth of 0–30 cm. Table 2 gives data on precipitation and temperature from January to July in 2004–2007. Fungicides, active ingredients and their contents in particular products are listed in Table 3.

The presence of *Fusarium* spp. was assessed using a PCR method. The following species of the genus *Fusarium* were found: *F. culmorum, F. graminearum, F. poae* and *F. avenaceum.*

Grain samples. Grain was harvested with a Sampo combine equipped with automated sampling of 2 kg from each 10-m^2 plot. These samples from four replicates were bulked in a blender (for 30 s) of which a sample of 2 kg was taken. This sample was homogenized using a laboratory blender to prepare a sample of 200 g. It was ground in a laboratory mill and passed over for further analyses.

Determination of trichothecene A and B type mycotoxin set. A new method employing high-performance liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS) was used for determination of trichothecene mycotoxins. The instrument used for measurements consisted of HP1100 Binary Series LC system (Agilent Technologies, USA) and a mass spectrometer with ion trap mass analyzer (Finnigan LCQ Deca, USA).

Standards and chemicals. Mycotoxin standards were purchased from Sigma-Aldrich (Germany), Biopure (Austria). Certified reference materials, DON in wheat flour (< 0.05 mg/kg, BCR 396, Belgium) and DON in naturally contaminated wheat (0.7 ± 0.1 mg/kg, R-Biopharm Rhone, UK), were used for quality assurance in mycotoxin analysis. Both analytical methods described below were accredited (ISO 17025) and as a part of external quality control the trueness of generated data was demonstrated through participation in Food Analysis Performance Assessment Scheme (FAPAS) organized by the Central Science Laboratory (York, UK).

Performance characteristics. Limits of detection (LOD) and quantification (LOQ), recoveries and repeatabilities (RSD), which were obtained within the validation process, are reported in Table 4.

Table 1. Agrochemical soil analyses, content of available nutrients (mg/kg) in 0–30 cm layer and pH

Crop rotation	Year	Preceding crop	Extraction by Mehlich III		0–30 cm	
			P (mg/kg)	K (mg/kg)	pH/KCl	N total (%)
Conventional	2004	oilseed rape	75	120	5.96	0.17
	2005	oilseed rape	75	114	6.82	0.23
	2006	oilseed rape	77	130	6.45	0.23
Organic	2004	clover	76	210	6.47	0.23
	2005	clover	93	231	6.40	0.22
	2006	clover	124	190	7.03	0.19

Table 2. Sums of precipitation and mean temperatures in every month

Month	Precipitation (mm)				Temperature (°C)			
	2004	2005	2006	N	2004	2005	2006	N
January	19.4	21.4	41.2	27.0	–3.2	0.5	–6.7	–2.2
February	33.3	51.3	34.4	25.0	1.0	–2.4	–2.3	–0.7
March	76.0	13.5	61.6	31.0	3.7	2.1	1.5	3.7
April	43.3	66.3	89.7	42.0	10.6	10.5	10.6	8.7
May	26.4	53.3	115.3	65.0	13.0	14.7	14.4	14.2
June	115.7	70.8	105.3	74.0	16.4	17.4	18.5	16.9
July	31.4	75.8	8.1	78.0	18.6	19.6	22.8	18.8
Sum	345.5	352.4	455.6	342.0				
Mean	49.4	50.3	65.1	48.9	8.6	8.9	8.4	8.5

N – normal (long-term mean 1971–2000)

Calibration curves for all analytes were linear within working range from 5 to 10 000 μg/kg. Squared correlation coefficients (R^2) were in the range 0.9991–0.9999 for 11 point calibration curves.

This work presents levels of DON mycotoxin content only.

Wheat quality evaluation. Bread-making quality of winter wheat cultivars grown under various cropping systems was evaluated using three parameters (TKW in g, volume weight in g/l, protein content in %). The method for determination of volume weight complied with ISO 7971-2 and the method for determination of protein content in dry matter with ICC standard No. 167.

Table 3. Fungicides, active ingredients and contents (g/l, %)

Fungicide	Active ingredients (g/l, %)
Bumper 25 EC	propiconazole 250
Topsin	thiophanate-methyl 70%
Artea 330 EC	cyproconazole 80
	propiconazole 250
Alert	carbendazim 250
	flusilazole 125
Capitan	flusilazole 250
Sfera	cyproconazole 80
	trifloxystrobin 187.5
Bravo	chlorothalonil 500
Amistar	azoxystrobin 250
Caramba	metconazole 60
Retacel	chlormequat-chloride 720
Modus	trinexapac-ethyl 250

RESULTS AND DISCUSSION

Grain yield and some other quality parameters (volume weight, protein content) (Tables 5–8)

Grain yield of winter wheat in organic cropping system was lower as compared to intensity in conventional cropping system because the yield and protein content correspond to nitrogen doses. All these systems significantly differed among each other. However, clover as a preceding crop to winter wheat in organic crop rotation ensured a sufficient amount of nitrogen for grain yield, which was 6.72 t/ha on average of the three years. Despite that the yield was significantly lower in all examined variants, it can still be profitable due to higher prices of organically grown products.

The grain yield in individual years was largely influenced by weather conditions (Table 2). The highest yields produced in both cropping systems in 2004 (7.26–9.53 t/ha in organic cropping system and 8.25–12.78 t/ha in conventional cropping system) when both the precipitation sum and temperature sum from January to July were near the normal. The yields were lower in the following two years. In 2005, the yields in organic cropping system ranged from 4.83 to 7.23 t/ha and from 7.48 to 10.08 t/ha in conventional cropping system. In 2006, they were between 4.49 and 6.44 t/ha in organic cropping system and between 6.35 and 10.16 t/ha in conventional cropping system. In

Table 4. Summary of validation data of LC-MS/MS method

	DON	NIV	Fus-X	ADONs	HT-2	T-2
LOD (μg/kg)	0.5	1.0	1.0	1.0	1.0	0.5
LOQ (μg/kg)	5.0	1.0	1.0	1.0	1.0	5.0
Recovery (%)*	70.6	53.3	83.1	82.8	95.4	83.5
	71.1	42.8	80.8	84.0	85.9	91.2
Repeatability (%)*	3.6	3.5	1.4	1.5	3.9	3.9
	3.1	9.7	7.1	6.5	6.0	4.0

LOD – limit of detection; LOQ – limit if quantification; *analytes' levels in spiked samples were 500 μg/kg

these years, the temperature in June and July, which was by 0.5–3°C higher as compared with the preceding year and long-term normal, played an important role. This yield variation in individual years was similar in both cropping systems. High productivity has been one of priorities of all cropping systems. Nevertheless, different weather conditions in each growing season are natural occurrence of variability (Kučerová 2005).

Another basic growing goal in all cropping systems is achieving sufficient quality. The requirement of the Czech national standard for bread wheat minimum value of protein content (11.5%) was met in conventional crop rotation in all cases. Average value of protein content in organic crop rotation met this limit too, but the protein content was below the required value in two cases. Based on volume weight, only H intensity of conventional crop rotation differed significantly from other variants. However, the required value (760 g/l) was met in majority of cases in organic crop rotation. Obtained results were fully comparable to L and M intensity of conventional crop rotation.

Table 5. Grain yield and other parameters of nine cultivars of winter wheat in the organic crop rotation (Kroměříž, 2004–2006)

Cultivar	Yield (t/ha)	TKW (g)	VW (g/l)	Protein content (%)
Batis	6.49	48.09	813	11.70
Bill	6.91	43.52	780	11.57
Complet	7.17	48.09	805	11.53
Contra	6.86	40.48	774	10.90
Drifter	6.99	43.85	784	11.23
Ebi	6.67	44.04	822	11.50
Estica	6.06	41.96	757	11.70
Ludwig	7.13	48.36	812	11.93
Sulamit	6.24	41.22	812	11.53
Mean	6.72	44.40	795	11.51

TKW – thousand-kernel weight; VW – volume weight

The yield and quality parameters depend, beside plant nutrition, on the occurrence of diseases that were not suppressed by using fungicides. On the other hand, however, the losses caused by diseases in the organic cropping system are often smaller than in conventional systems. It is partially explained by lower yields of organic crops and other factors such as low N status of the crop reducing susceptibility to diseases. However, both high grain yields and good quality were obtained in our experiments, probably due to specific effects of crops in the crop rotation.

Occurrence of *Fusarium* spp. and DON content

In our three-year experiments, the DON content was measured in grain of nine winter wheat cultivars under organic and conventional cropping systems. The cultivars were always grown after such preceding crops whose post-harvest residues were incorporated into soil and after preceding crops (clover and oilseed rape) that are not host crops for *Fusarium* spp. The occurrence of FHB was low in both crop rotations. The three-year results document a high production potential of the designed organic crop rotation as well as good health state of the examined cultivars of winter wheat, including satisfactory levels of mycotoxin concentration in grain (Table 9).

In the organic crop rotation, the occurrence of *Fusarium* spp. as well as mycotoxin content in grain were low (average levels of DON in the examined

Table 6. Grain yield and other parameters of nine cultivars of winter wheat in the conventional crop rotation after oilseed rape as preceding crop, at low growing intensity (Kroměříž, 2004–2006)

Cultivar	Yield (t/ha)	TKW (g)	VW (g/l)	Protein content (%)
Batis	8.00	42.67	818	13.03
Bill	8.45	38.67	782	12.87
Complet	8.78	43.10	811	12.43
Contra	8.00	36.00	769	12.93
Drifter	7.90	40.00	780	13.77
Ebi	7.46	40.87	819	13.23
Estica	7.58	37.13	763	13.30
Ludwig	7.87	43.57	816	13.83
Sulamit	7.60	39.57	820	12.77
Mean	7.96	40.17	798	13.13

TKW – thousand-kernel weight; VW – volume weight

Table 7. Grain yield and other parameters of nine cultivars of winter wheat in the conventional crop rotation after oilseed rape as preceding crop, at medium growing intensity (Kroměříž, 2004–2006)

Cultivar	Yield (t/ha)	TKW (g)	VW (g/l)	Protein content (%)
Batis	8.25	41.53	817	12.90
Bill	8.79	38.90	786	12.87
Complet	9.41	43.57	807	13.13
Contra	8.38	35.37	770	13.20
Drifter	8.20	38.90	771	14.47
Ebi	8.11	41.57	825	13.63
Estica	7.87	37.57	766	13.53
Ludwig	8.38	43.57	811	14.57
Sulamit	8.02	38.43	820	13.50
Mean	8.38	39.93	797	13.53

TKW – thousand-kernel weight; VW – volume weight

cultivars were 299.9 μg/kg in 2004; 123.6 μg/kg in 2005 and 30.0 μg/kg in 2006) and did not surpass the limit settled for bread wheat (1 250 μg/kg, EC No. 856/2005) in any year; maximum detected DON content was 439.9 μg/kg (cv. Contra in 2004).

In the conventional crop rotation, the DON content was higher in 2004 as compared with that in the organic crop rotation (299.9 μg/kg) at all growing intensities (L – 734.8 μg/kg, M – 864.6 μg/kg and H – 417.6 μg/kg). The limit for bread wheat was exceeded in one case (1 433.6 μg/kg, cv. Complet).

Very small differences were found in 2005 when the occurrence of *Fusarium* spp. was very low (the organic crop rotation – 123.6 μg/kg and L – 141.7 μg/kg, M – 92.2 μg/kg and H – 86.7 μg/kg), and the limit for bread wheat was not exceeded in any case.

In 2006, the average mycotoxin concentration in grain was very low in the organic crop rotation (30.0 μg/kg). In the conventional crop rotation, DON content was higher in comparison with the year 2005 (L – 165.9 μg/kg, M – 213.6 μg/kg and H – 222.4 μg/kg).

These results confirm a great importance of preceding crop and tillage system (Schaafsma et al. 2005). The determined levels of DON were very low in both cropping systems under study. There was no significant difference in the DON content between winter wheat grain from organic crop rotation and conventional crop rotation at H intensity. Likewise, Edwards and Ray (2005) report no difference in DON mycotoxin content between organic and conventional crop rotation, as organic growers usually follow a non-cereal crop and plough. Winter wheat rarely follows maize.

In contrast, Czajkowska et al. (1999) report higher incidences of a number of diseases, including FHB, in organic crop rotation. This documents the effect of location and incites a question of selecting a site suitable for organic cropping system. The relative contribution of external and within-field inoculum sources to FHB was descussed (Del Ponte et al. 2003) and they concluded that the spores immigrants to wheat fields are important contributors to FHB epidemics in wheat fields planted after nonhost crops. Adjacent crops, the local crop scale and field size may increase the FHB infection potential.

Fusarium head blight (FHB) is an important disease worldwide. Its increasing incidence has been attributed to reduced tillage and more crop residues that are host plants on the soil surface.

The disease makes significant yield reduction and low quality of grain but also results in the contamination of grain by numerous mycotoxins as secondary metabolites. In addition to DON, five other mycotoxins were studied (NIV, sum of ADON, HT-2, T-2, ZON), however, only DON, the most common *Fusarium* toxin produced on winter wheat in the Czech Republic, is presented in this work.

Agricultural measures may thus contribute to the reduction in the risk of FHB disease and toxin

Table 8. Grain yield and other parameters of nine cultivars of winter wheat in the conventional crop rotation after oilseed rape as preceding crop, at high growing intensity (Kroměříž, 2004–2006)

Cultivar	Yield (t/ha)	TKW (g)	VW (g/l)	Protein content (%)
Batis	9.95	42.87	823	13.70
Bill	10.36	38.90	784	14.23
Complet	10.96	42.43	813	13.50
Contra	9.71	35.33	781	13.53
Drifter	9.77	40.00	789	14.83
Ebi	9.80	43.77	828	13.73
Estica	9.42	38.70	786	14.20
Ludwig	10.21	43.67	824	14.67
Sulamit	9.59	38.90	824	14.13
Mean	9.97	40.51	806	14.06

TKW – thousand-kernel weight; VW – volume weight

Table 9. Mycotoxin DON content in nine cultivars of winter wheat in the organic crop rotation and in the conventional crop rotation after oilseed rape as preceding crop, at three growing intensities (Kroměříž, 2004–2006)

Cultivar	DON (µg/kg)			
	O	L	M	H
Batis	147.40	369.37	280.47	254.30
Bill	153.67	408.23	470.93	338.10
Complet	158.00	506.47	587.70	447.27
Contra	172.10	297.50	382.50	226.37
Drifter	117.57	293.17	434.90	194.70
Ebi	134.27	278.33	384.20	193.00
Estica	241.97	198.33	247.97	150.30
Ludwig	87.47	375.50	260.90	225.77
Sulamit	148.40	400.47	461.63	186.93
Mean	151.20	347.49	390.13	246.30

DON – deoxynivalenol; O – organic crop rotation; L – conventional crop rotation, low intensity; M – conventional crop rotation, medium intensity; H – conventional crop rotation, high intensity

contamination. These factors are especially a balanced crop rotation of cereals and non-cereal crops, avoidance of maize as a preceding crop and soil tillage through which a reduction in disease severity may be achieved. A direct measurement to reduce FHB would consist in chemical control (Matthies and Buchenauer 2000). Protective treatments with fungicides reduced FHB by 40–60%. Researchers have been developing more resistant cultivars, better spraying technology and more effective fungicides against FHB (Siranidou and Buchenauer 2001, Mesterházy et al. 2003).

Fusarium occurrence in ears as well as DON content in our grain samples were low and the limit (DON 1 250 µg/kg) given by the EU, Amended Fusarium Toxin Levels 1881/2006, was not exceeded in any of the examined variants in any of the two cropping systems. However, the average value of DON content observed in organic crop rotation differed significantly from average values observed in L and M intensities of conventional crop rotation. The difference between H intensity and organic system was not significant (Table 10). Similarly, Edwards and Ray (2005) indicated that no significant difference was found for DON concentration between organic and conventional wheat samples that were analysed in the UK.

The area of organic production has been increasing. The supermarkets have begun to play a much more important role in marketing organic products. This has had a direct influence on production practices, especially as regards increased demands for the reduction of *Fusarium* mycotoxin accumulation in wheat. The value of crop rotations and crop type in rotations in control of *Fusarium* spp. has been neglected in the conventional crop rotation. In the organic crop rotation, it can be a key factor in protection against many diseases, including *Fusarium* spp.

Table 10. Comparison of the four systems of winter wheat cultivation – average values of grain yield and other parameters, homogeneous groups (α = 0.05) (Kroměříž, 2004–2006)

System	Yield	TKW	VW	Proteins	DON
O	6.72[a]	44.40[b]	795.37[a]	11.51[a]	151.20[a]
L	7.96[b]	39.93[a]	797.59[a]	13.13[b]	347.49[b, c]
M	8.38[c]	40.17[a]	797.00[a]	13.53[c]	390.13[c]
H	9.97[d]	40.51[a]	805.78[b]	14.06[d]	246.30[a, b]

TKW – thousand-kernel weight; VW – volume weight; DON – deoxynivalenol; O – organic crop rotation; L – conventional crop rotation, low intensity; M – conventional crop rotation, medium intensity; H – conventional crop rotation, high intensity

This work gathered the arguments to discuss on whether organic grain products can be affordable for dietary and food safety demands.

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