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Mycotoxins in organically versus conventionally produced cereal grains and some other crops in temperate regions

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REVIEW ARTICLE

Abstract

This paper presents peer-reviewed studies comparing the content of deoxynivalenol (DON), HT-2+T-2 toxins, zearalenone (ZEA), nivalenol (NIV), ochratoxin A (OTA) and fumonisins in cereal grains, and patulin (PAT) in apple and apple-based products, produced in organically and conventionally grown crops in temperate regions. Some of the studies are based on data from controlled field trials, however, most are farm surveys and some are food basket surveys. Almost half of the studies focused on DON in cereals. The majority of these studies found no significant difference in DON content in grain from the two farming systems, but several studies showed lower DON content in organically than in conventionally produced cereals. A number of the investigations reported low DON levels in grain, far below the EU limits for food. Many authors suggested that weather conditions, years, locations, tillage practice and crop rotation are more important for the development of DON than the type of farming. Organically produced oats contained mainly lower levels of HT-2+T-2 toxins than conventionally produced oats. Most studies on ZEA reported no differences between farming systems, or lower concentrations in organically produced grain. For the other mycotoxins in cereals, mainly low levels and no differences between the two farming systems were reported. Some studies showed higher PAT contamination in organically than in conventionally produced apple and apple products. The difference may be due to more efficient disease control in conventional orchards. It cannot be concluded that any of the two farming systems increases the risk of mycotoxin contamination. Despite no use of fungicides, an organic system appears generally able to maintain mycotoxin contamination at low levels. More systematic comparisons from scientifically controlled field trials and surveys are needed to clarify if there are differences in the risk of mycotoxin contamination between organically and conventionally produced crops.

Keywords: deoxynivalenol, HT-2+T-2 toxins, zearalenone, nivalenol, ochratoxin A, fumonisins, patulin

1. Introduction

Mycotoxin contaminated cereal grain may represent a health risk when consumed by humans and livestock. Mycotoxins are also commonly detected in fruits, vegetables and other crops (Barkai-Golan and Paster, 2008). Some mycotoxins are produced by fungi infecting plants in the field during the growing season, while others are mainly produced postharvest by fungi growing on plant products during drying and storage. Some species within the fungal genera *Fusarium*, *Penicillium*, *Aspergillus* and *Alternaria* are important mycotoxin producers. The most important toxins in temperate regions in terms of health hazards are:

- Deoxynivalenol (DON) and other trichothecenes (e.g. nivalenol (NIV), T-2 toxin (T-2), HT-2 toxin (HT-2)), zearalenone (ZEA), and fumonisins produced by *Fusarium* spp.
- Ochratoxin A (OTA), produced by *Penicillium* spp. and *Aspergillus* spp.
- Patulin (PAT) produced by *Penicillium* and *Aspergillus* spp.

Fungal infection and production of mycotoxins in plants depend on temperature, humidity, host species and cultivars, agronomy and other environmental conditions. An important question is whether the farming system has an impact on fungal infection of plants and development of mycotoxins. Synthetic fungicides and mineral fertilisers are not used in organic production. Therefore, it has been questioned whether organically grown crops are more prone to fungal infection and mycotoxin contamination than conventionally grown crops (e.g. Lairon, 2010; Magkos *et al.*, 2006; Rossi *et al.*, 2006).

Due to increased demand for organically produced food, scientific assessments of the quality of products from different farming systems are justified. A number of scientific surveys and studies from European and a few other temperate countries have compared the mycotoxin content of organically and conventionally (including integrated) produced crops, especially of cereals, but also some studies of apples and a few other crops have been published. The aim of this review is to give an overview of these studies, with focus mainly on raw materials. Data on mycotoxins in some processed food and food products were included, mainly when they were part of a study where mycotoxin content was not determined in raw materials separately. The review is based on a risk assessment from the Norwegian Scientific Committee on Food Safety (2014) and supplemented with more recently published results.

Some of the studies presented in the review are based on mycotoxin analysis of cereal grains and plant material originating from controlled field trials, however, most are farm surveys and some are food basket surveys. The quantities of mycotoxins were reported as proportions of mycotoxin contaminated samples, as well as concentration levels given as means of positive samples and/or mean of all samples, and/or as median levels.

Several challenges are encountered when using surveys to compare quality aspects of crops and products from organic and conventional farming (Jensen *et al.*, 2013b; Lester and Saftner, 2011). There may be variations in farming practice (cultivar, sowing and harvesting date, sampling time, crop rotation, tillage practice) between organic and conventional systems, as well as between individual farms both within organic and within conventional farming. In addition, environmental conditions such as soil properties and local weather may vary within the dataset, and particularly in food basket surveys, the grain may have very different origin. Comparisons are more reliable in experimental field trials. In farm surveys, some of the variations can be met by collecting samples at the same time from organic and conventional farms close to each other, but different conditions on the sampling site will influence on the comparison of organic/conventional production. For basket surveys, variation due to blending and processing of different yield lots will add to the variation.

Due to the large variations in reporting, statistical analyses, analytical methods and limits of detection of the different methods, and the variations related to farming practice, it is challenging to reach a clear conclusion from different comparisons. Moreover, a number of the studies included only a limited number of samples. In spite of these uncertainties, we have summarised a number of peer-reviewed studies where a statistically significant difference or no difference between the farming systems was reported. Also some studies with insufficient statistical documentation were included, partly due to a comprehensive number of samples tested, and partly due to few available studies with statistical analyses, as for OTA.

2. Mycotoxins in cereals

In temperate climate cereals constitute a major part of the agricultural commodities contaminated by mycotoxins.

Deoxynivalenol

In total, 33 studies comparing DON content in organically and conventionally produced cereal grains have been assessed. Some studies compared DON content in more than one cereal species. Organically and conventionally produced wheat were included in 26 of the studies (30 comparisons), including two durum wheat studies, whereas oats, barley and rye were included in five studies each, and maize and rice in two each; altogether there were 46 comparisons. The majority of the studies found no significant differences in DON content in cereals from the two farming systems (Table 1). Four studies reported higher DON content in organically compared to conventionally produced cereals, and 16 studies reported lower DON content in organically than in conventionally produced cereals.

In a comprehensive study in the UK, including 247 samples of organically and 1,377 samples of conventionally produced wheat grain, no significant differences in DON content were found in grain from the two farming systems; a mean DON level of 230 μg/kg was reported for the organically and conventionally produced wheat (Edwards, 2009b). No differences in DON content in wheat from the two farming systems were also reported in studies from several other countries; the Netherlands (Hoogenboom *et al.,* 2008), Switzerland (Griesshaber *et al.*, 2004; Mäder *et al.*, 2007), France (Champeil *et al.*, 2004; Malmauret *et al.*, 2002), Germany (Berleth *et al.*, 1998; Marx *et al.*, 1995) and Norway (Eltun, 1996), as well as in a study of wheat bran from Spain (Vidal *et al.*, 2013). The authors suggested that yearly variation was more important for DON contamination than farming practices. Wheat from a Canadian low-input system field trial in 2009 had a lower DON content (organic: 3,900 μg/kg) than wheat from a high-input system (conventional: 5,500 μg/kg) (Munger *et al.*, 2014). The high DON content in that field trial co-

Table 1. Overview of studies comparing deoxynivalenol content (percentage contaminated samples, mean of positive or all samples, and/or median concentration levels) in cereal grains from organic (Org) and conventional (Conv) farming.[1]

Cereal species	Country	Sampling years	Study type[2]	Number of samples org/conv	% contam. samples org/conv	Mean (µg/kg) of positive org/conv	Mean (µg/kg) of all samples org/conv	Median (µg/kg) org/conv	Org vs conv[3]	Reference
Wheat	Slovenia	2008-2012	FS	21 / 44	52 / 73	599 / 331			O>C[4]	Kirincic *et al.*, 2015
Wheat	Canada	2009	FT	12 / 12			3,900 / 5,500		O<C	Munger *et al.*, 2014
		2010		12 / 12			340 / 460		O=C	
Wheat (bran)	Spain	2012	BS	11 / 26	72 / 58	655 / 1,657		426 / 923	O=C	Vidal *et al.*, 2013
Durum wheat	Spain	2006-2007	FS	50 / 67	28 / 31		95 / 194		O=C	Gimenez *et al.*, 2012
Wheat	Slovakia	2007-2008	FT				192 / 361		O<C	Lacko-Bartosova and Kobida, 2011
Durum wheat	Italy	2006-2008	FT	108 / 108			31 / 86.5		O<C	Quaranta *et al.*, 2010
Wheat	Norway	2002-2004	FS	92 / 92			86 / 170	29 / 51	O<C	Bernhoft *et al.*, 2010
Wheat	UK	2001-2005	FS	247 / 1,377	86		230	42	O=C	Edwards, 2009b
Wheat	Germany	2000-2007	FS	110 / 355	23 / 42		55 / 242 [5]		O<C[4]	Meister, 2009
Wheat	The Netherlands	2003-2004	FS	22 / 17	91 / 82		950 / 1,100		O=C	Hoogenboom *et al.*, 2008
Wheat	Czech Republic	2004-2006	FT			Mean level 151 (org) / 246 (conv with fungicide)			O=C	Vanova *et al.*, 2008
						Mean level 151 (org) / 390 (conv without fungicide)			O<C	
Wheat	Switzer land	1998-2000	FT				27-74 /10-140		O=C	Mäder *et al.*, 2007
Wheat	Poland	2003	FS	12 / 15	42 / 60	Mean level 40 (org) / 18 (conv with fungicide)			O>C	Perkowski *et al.*, 2007
				12 / 5	42 / 100	Mean level 40 (org) / 612 (conv without fungicide)			O<C	
Wheat	Lithuania	2003	FS	11 / 13	100	115 / 138	115 / 138		O<C	Bakutis *et al.*, 2006
Wheat	Italy			20 / 15	25 / 100		2.9 / 100		O<C	Rossi *et al.*, 2006
Wheat	Belgium	2002-2003	FS	51 / 42	98 / 98		204 / 493		O<C	Pussemier *et al.*, 2006
Wheat	Germany	1999-2001	FT	40 / 40		Annual mean levels Nd[6] -1,081 (org) / Nd[6]-711 (conv)			O<C[4]	Schneweis *et al.*, 2005
Wheat	France	2000-2002	FT			Mean level 265 (org) / 457 (conv with fungicide)			O=C	Champeil *et al.*, 2004
						Mean level 730 (org) / 288 (conv without fungicide)				
Wheat	Switzerland	1998-2000	FT	16 / 16	100		61 / 82		O=C	Griesshaber *et al.*, 2004
Wheat and products	Italy		BS	36 / 44	69 / 77			38 / 65	O<C	Cirillo *et al.*, 2003
Wheat	Germany	1997-1998	FT			Mean level 200 (org) / 150 (conv with fungicide)			O=C	Birzele *et al.*, 2002
						Mean level 200 (org) / 375 (conv without fungicide)			O<C	
Wheat	Germany	1998	FS	46 / 150	54 / 69	760 /1540		230 /270	O<C[3]	Döll *et al.*, 2002
Wheat	France		FS	11 / 11	54 / 91			106 / 55	O=C	Malmauret *et al.*, 2002
Wheat	Norway	1990-1993	FT			Annual mean levels 21-99 (org) / 10-70 (conv)			O=C	Eltun, 1996
Wheat	Germany	1991	FS	50 / 51	76 / 88	486 / 420			O=C[4]	Marx *et al.*, 1995

Table 1. Continued.

Cereal species	Country	Sampling years	Study type[2]	Number of samples org/conv	% contam. samples org/conv	Mean (µg/kg) of positive org/conv	Mean (µg/kg) of all samples org/conv	Median (µg/kg) org/conv	Org vs conv[3]	Reference
Wheat and rye	Germany	1994-1996	FS	329	100	Annual mean levels 19.2-57.2 (org) / 19.3-71.5 (conv)			O=C	Berleth *et al.*, 1998
Oats	Poland	2006-2008	FS	36 / 22	97 / 78	636 / 697		640 / 740	O=C	Kuzdralinsky *et al.*, 2013
Oats	Poland	2009-2011	FS	34 / 24	20 / 85	33 / 29		23 / <LOQ [7]	O>C	Twaruzek *et al.*, 2013
Oats	Norway	2002-2004	FS	101 / 101			114 / 426	24 / 36	O=C	Bernhoft *et al.*, 2010
Oats	Finland	1997-1998	FT	56 / 55		Level ranges 25-345 (org) / 25-526 (conv)			O=C	Hietaniemi *et al.*, 2004
Oats	Norway	1990-1993	FT			Annual mean levels 23-50 (org) / Nd[6]-38 (conv)			O=C	Eltun, 1996
Barley	Norway	2002-2004	FS	108 / 108			44 / 44	<20 / <20	O=C	Bernhoft *et al.*, 2010
Barley	UK	2002-2005	FS	108 / 338	57		19	11	O=C	Edwards, 2009c
Barley	Lithuania	2003	FS	11 / 13	82 / 100	138 / 110	113 / 110		O=C	Bakutis *et al.*, 2006
Barley	France		FS	5 / 5	60 / 80			69 / 41	O=C	Malmauret *et al.*, 2002
Rye	Poland	2009-2012	FS	52 / 24	37 / 79		<15 / 46	2.5 / 15	O<C	Blajet-Kosicka *et al.*, 2014
Rye	Germany	2000-2007	FS	173 / 337	14 / 36		<50 / 64 [5]		O<C[4]	Meister, 2009
Rye	Germany	1998	FS	19 / 50	11 / 34	130 / 490		<111 / <111	O=C[4]	Döll *et al.*, 2002
Rye	Germany	1991	FS	50 / 50	56 / 40	427 / 160			O>C[4]	Marx *et al.*, 1995
Maize	Spain	2010-2011	FT	108 / 108	97		450 / 600 (Basque) 380 / 380 (Galicia)		O=C	De Galarreta *et al.*, 2015
Rice and products	Italy		BS	11 / 13	91 / 85			65 / 207	O<C	Cirillo *et al.*, 2003
Cereals (barley, rice, maize)	Rep. of Korea	2009	BS	88 / 99	40 / 38 (all samples)	59 / 47 (all samples)		23 / 28 (all samples)	O=C (all samples)	Ok *et al.*, 2011

[1] Empty cells imply data is not available.
[2] FS: field survey; BS: basket survey; FT: field trial.
[3] O: organic; C: conventional; O<C: organic significantly lower than conventional; O>C: organic significantly higher than conventional; O=C: no significant difference between organic and conventional.
[4] Statistical analysis not shown.
[5] Mean values of all samples are calculated means based on information in the papers (means of positive samples, yearly means or means of other subgrouped samples).
[6] Nd: not detected.
[7] LOQ: level of quantification.

Table 2. Overview of studies comparing HT-2+T-2 toxins content (percentage contaminated samples, mean of positive or all samples, and/or median concentration levels) in cereal grains from organic (Org) and conventional (Conv) farming systems.[1]

Cereal species	Country	Sampling years	Study type [2]	No of samples org/conv	% contam. samples org/conv	Mean (µg/kg) of positive org/conv	Mean (µg/kg) of all samples org/conv	Median (µg/kg) org/conv	Org vs conv[3]	Reference
Wheat	UK	2001-2005	FS	247 / 1,377	20 / 36	19 / 23			O<C	Edwards, 2009b
Wheat	Lithuania	2003	FS	11 / 13	82 / 69 (T-2)	54 / 36	44 / 25		O>C	Bakutis *et al.*, 2006
Wheat	Switzerland	1998-2000	FT	16 / 16	19/44 (HT-2)		Level ranges: <1-13 / <1-14	<1 / <1	O=C	Griesshaber *et al.*, 2004
Wheat	France		FS	11 / 11	9 / 0 (HT-2)			50 / –	–[4]	Malmauret *et al.*, 2002
Oats	Poland	2006-2008	FS	36 / 22	33 / 35 (HT-2) 39 / 48 (T-2)	192 / 229 95 / 123		90 / 175 81 /114	O=C	Kuzdralinsky *et al.*, 2013
Oats	Poland	2009-2011	FS	34 / 24	83 / 100 (HT-2) 61 / 90 (T-2)	11 / 38 3.5 / 19		8 / 23 2.5 /6	O<C	Twaruzek *et al.*, 2013
Oats	Norway	2002-2004	FS	101 / 101			80 / 117 (HT-2) 30 / 43 (T-2)	<20 / 62 <30 / <30	O<C	Bernhoft *et al.*, 2010
Oats	UK	2002-2005	FS	115 / 343	78/97	238 / 687	50/264	49 / 292	O<C	Edwards, 2009a
Oats (and products)	Germany	2005	FS/BS	35 / 35	100 /100		7.6 / 27		O<C	Gottschalk *et al.*, 2007
Barley	Norway	2002-2004	FS	108 / 108			<20 / 21 (HT-2)	<20 / <20	O<C	Bernhoft *et al.*, 2010
Barley	UK	2002-2005	FS	108 / 338	36% of total samples	no difference in mean levels (data not shown)			O=C	Edwards, 2009c
Barley	Lithuania	2003	FS	11 / 13	73 / 82 (T-2)	29 / 35	21 / 29		O<C	Bakutis *et al.*, 2006
Barley	France		FS	5 / 5	40 / 0 (HT-2)			50 / –	–[4]	Malmauret *et al.*, 2002
Rye	Poland	2009-2012	FS	52 / 24	21 / 42 (HT-2) 27 / 38 (T-2)		Nd[5] / <6.0 <2.0 / <2.0		O=C	Blajet-Kosicka *et al.*, 2014

[1] Empty cells imply data is not available.

[2] FS: field survey; BS: basket survey; FT: field trial.

[3] O: organic; C: conventional; O<C: organic significantly lower than conventional; O>C: organic significantly higher than conventional; O=C: no significant difference between organic and conventional.

[4] Statistical analysis not shown.

[5] Nd: not detected.

occurred with a 50% higher than normal precipitation in July. However, in 2010, with drier and warmer weather, and considerably lower DON levels (340 μg/kg in organically and 460 μg/kg in conventionally produced wheat grain), DON contamination was not affected by the farming system (Munger *et al.*, 2014). In three studies from Germany (Döll *et al.*, 2002; Meister, 2009; Schneweis *et al.*, 2005) lower DON levels were detected in organically than in conventionally produced wheat. Similar results were found in studies from Slovakia (Lacko-Bartosova and Kobida, 2011), Norway (Bernhoft *et al.*, 2010), Lithuania (Bakutis *et al.*, 2006), Italy (Cirillo *et al.*, 2003; Rossi *et al.*, 2006) and Belgium (Pussemier *et al.*, 2006). Three studies, one from Germany (Birzele *et al.*, 2002), one from Poland (Perkowski *et al.*, 2007) and one from the Czech Republic (Vanova *et al.*, 2008), reported higher DON content in conventionally grown wheat produced without fungicide application compared to organically produced wheat. However, when fungicides, with effect against *Fusarium*, were used in conventional production, either lower DON content was found in the conventionally than in the organically produced wheat (Perkowski *et al.*, 2007), or no difference was seen in grain from the two farming systems (Birzele *et al.*, 2002; Vanova *et al.*, 2008). From Slovenia, Kirincic *et al.* (2015) reported higher DON concentrations in samples from organic farming (mean 599 μg/kg) than in wheat from conventional farming (mean 331 μg/kg), although no statistical analysis was shown. A study of durum wheat from Italy reported lower DON levels in organically than in conventionally produced grain (Quaranta *et al.*, 2010). However, in a Spanish study, no difference in DON content was detected in durum wheat from the two farming systems (Gimenez *et al.*, 2012).

In studies of oats from Poland (Kuzdralinsky *et al.*, 2013), Norway (Bernhoft *et al.*, 2010; Eltun, 1996) and Finland (Hietaniemi *et al.*, 2004), no differences in DON levels were found in grain from the two farming systems. Another study from Poland reported higher DON levels in organically (median 23 μg/kg) than in conventionally produced (median < limit of quantification) oat grains (Twaruzek *et al.*, 2013). In two comprehensive surveys of barley, one from UK (Edwards, 2009c) and one from Norway (Bernhoft *et al.*, 2010), no differences in DON contaminations were found in samples of organically and conventionally produced grains. The median DON concentrations of the samples were low in both studies; 11 μg/kg (Edwards, 2009c) and <20 μg/kg (Bernhoft *et al.*, 2010) in average for samples from both farming systems. Also, in two limited studies, one from France (Malmauret *et al.*, 2002), and one from Lithuania (Bakutis *et al.*, 2006), no DON differences were found in barley samples from the two farming systems. In one study from Germany there was no difference in DON content in rye grain from the two farming systems (Döll *et al.*, 2002), whereas lower DON levels were detected in organically than in conventionally produced rye in another German study (Meister, 2009) as well as in a Polish study (Blajet-Kosicka *et al.*, 2014). In another German study, Marx *et al.* (1995) found higher DON levels in organically compared to conventionally grown rye (mean levels of positive samples 427 μg/kg and 160 μg/kg, respectively), although no statistical analysis was shown. In a comprehensive two year field trial with nine maize varieties at four locations in Spain, De Galarreta *et al.* (2015) found no differences in DON content of maize from the two farming methods. No difference in DON contamination between organically and conventionally produced maize was also reported from a basket survey in South Korea (Ok *et al.*, 2011). One study reported lower median levels of DON in organically than in conventionally produced rice (65 μg/kg and 207 μg/kg, respectively) (Cirillo *et al.*, 2003), while another study found no differences in rice from the two farming systems (Ok *et al.*, 2011).

Although no significant differences were found in the majority of the DON comparisons, several of these studies showed a tendency of lower DON content in organically than in conventionally produced cereals. Together with the studies reporting lower DON in organically than in conventionally produced grain, this indicates that it is unlikely that organic farming increases the DON risk. A systematic review, calculating summary effect sizes of seven studies, reported lower levels and lower risk for DON in organically than in conventionally produced wheat (Smith-Sprangler *et al.*, 2012), although the authors pointed out that one large study (Edwards, 2009b), which did not report sufficient detail to be included in the calculations, found no differences in DON concentrations. However, many of the investigations assessed above (Table 1) reported low DON concentration levels in grain from both farming systems. Mostly the levels were far below the EU limits for food: 1,250 μg/kg for wheat, barley and rye and 1,750 μg/kg for oats and durum wheat (EC, 2006). Several authors commented that weather conditions, cropping year, locations, crop rotation and tillage practice may be more important for the development of DON than the type of farming (e.g. Bakutis *et al.*, 2006; Bernhoft *et al.,* 2010; Champeil *et al.*, 2004; De Galarreta *et al.*, 2015; Gimenez *et al.*, 2012; Griesshaber *et al.*, 2004; Hoogenboom *et al.*, 2008; Meister, 2009; Munger *et al.*, 2014; Quaranta *et al.*, 2010).

HT-2 and T-2 toxins

A total of 11 studies, comparing the content of HT-2 and T-2 (alone or combined) in cereal grains from organic versus conventional farming systems, have been included. As some of these studies included more than one cereal species, there were altogether 14 comparisons. Wheat was included in four comparisons, oats in five, barley in four, and rye in one comparison. In six of the studies, no significant differences in HT-2 and T-2 content of cereals from the two farming systems were detected. In half of the comparisons, significantly lower HT-2 and/or T-2 contamination was detected in organically compared to conventionally grown cereals (Table 2). A higher T-2 level was reported in wheat from organic, compared to conventional farming in one study.

In a study of wheat from organic versus conventional farming systems in Switzerland, no difference in HT-2+T-2 levels was detected between the two farming systems (Griesshaber *et al.*, 2004). In a study of wheat in UK during 2001-2005, the predicted incidence of HT-2+T-2 in grain from organic production systems was about half that of the grain from conventional production systems (Edwards, 2009b). On the contrary, T-2 content in wheat from organic farming systems in Lithuania was 43% higher than the content in wheat from conventional farming (Bakutis *et al.*, 2006). Likewise, HT-2 levels above detection limit were only found in samples from organically produced wheat in a French study (Malmauret *et al.*, 2002), while no HT-2 was detected in conventionally produced wheat. In oats, there was only one study where no significant difference in HT-2+T-2 content was detected in grain from organic and conventional production systems (Kuzdralinsky *et al.*, 2013). In a Norwegian farm survey during the years 2002-2004 the levels of HT-2+T-2 were significantly lower in oats from organic compared with conventional production systems (Bernhoft *et al.*, 2010). In an English survey the predicted mean for HT-2+T-2 content in oats from organic production systems was five times lower than in oats from conventional production systems (Edwards, 2009a). Significantly lower HT-2+T-2 levels were also detected in oat grains and oat products from organic compared to conventional farming systems in a German survey performed in 2005 (Gottschalk *et al.*, 2007), as well as in a study of oats in Poland during 2009-2011 (Twaruzek *et al.*, 2013). No significant difference in T-2+H-T2 incidence was detected in samples from organically and conventionally grown barley in UK during 2002-2005 (Edwards, 2009c). Lower HT-2 levels were detected in barley from organic compared with conventional production systems in Norway (Bernhoft *et al.*, 2010). In Lithuania, lower T-2 levels were detected in barley from organic farming systems compared to conventional farming systems (Bakutis *et al.*, 2006). However, in a French study, HT-2 was only detected in organically produced barley (Malmauret *et al.*, 2002), while no HT-2 was detected in conventionally produced barley

From the overview presented here, we conclude that lower HT-2+T-2 levels are more often detected in oat grains from organic compared to conventional production systems. For the other cereals species, no clear conclusions can be drawn mainly due to inconsistency in the results and the low mycotoxin levels. An organic farming system often practice more frequent mouldboard ploughing, and grow cereals more often in rotation with non-cereals, than conventional farming (Finckh and Van Bruggen, 2015), which may reduce infection, and could partly explain the lower HT-2+T-2 concentrations reported in organically grown oats. Moreover, whereas DON producing *Fusarium* fungi are partly controlled by fungicides in conventional farming, these fungicides have been reported to have limited or no effect on T-2 and HT-2 producing *Fusarium* (Edwards and Anderson, 2011).

Zearalenone

A total of 13 papers from European countries compared the concentrations of ZEA in organically and conventionally produced cereals (Table 3). Three papers presented comparable results from two cereal species, and ten papers presented results from one cereal species. There were ten comparisons in wheat, one in oats, two in barley and three in rye (altogether 16 comparisons). Most studies were surveys based on grain sampled at different farms; one was a basket study, whereas two studies were conducted experimentally in the field.

In five studies there were no differences in ZEA content between organically and conventionally produced wheat (Döll *et al.*, 2002; Edwards, 2009b; Hoogenboom *et al.*, 2008; Lacko-Bartosova and Kobida, 2011; Vidal *et al.*, 2013). Four wheat studies showed lower ZEA concentrations in samples from organic than in samples from conventional farming (Bakutis *et al.*, 2006; Meister, 2009; Pussemier *et al.*, 2006; Schneweis *et al.*, 2005). One study reported higher ZEA concentrations in organically than in conventionally produced wheat (Marx *et al.*, 1995). The study in oats showed no difference in ZEA concentrations in samples from the two farming systems (Twaruzek *et al.*, 2013). Of the two studies in barley, one showed no difference in ZEA concentrations (Ibáñez-Vea *et al.*, 2012), whereas the other had lower concentrations in organically than in conventionally produced barley (Bakutis *et al.*, 2006). Of the studies in rye, one reported no difference in ZEA concentrations in samples from the two farming systems (Blajet-Kosicka *et al.*, 2014), one showed lower ZEA concentrations in the organically than in the conventionally produced rye, (Meister, 2009) and one showed higher ZEA concentrations in organically than in conventionally produced rye (Marx *et al.*, 1995).

The large variations in ZEA concentrations in the cereal samples reflect the range of factors influencing these concentrations. Large variation, relatively low number of samples in some of the studies and the fact that ZEA is often below the level of detection in a considerable part of the cereal samples reduces the possibility to reveal statistically significant differences between organic and conventional farming practices.

Table 3. Overview of studies comparing zearalenone concentration (percentage contaminated samples, mean of positive or all samples, and/or median concentration levels) in cereal grains from organic (Org) and conventional (Conv) farming systems.[1]

Cereal species	Country	Sampling years	Study type[2]	Number of samples org/conv	% contam. samples org/conv	Mean (µg/kg) of positive org/conv	Mean (µg/kg) of all samples org/conv	Median (µg/kg) org/conv	Org vs conv[3]	Reference
Wheat bran	Spain	2012	BS	11 /26	9 / 15	21 / 4			O=C	Vidal *et al.*, 2013
Wheat	Slovakia	2007-2008	FT				7.9 / 7.4		O=C	Lacko-Bartosova and Kobida, 2011
Wheat	Germany	2001-2007	FS	94 / 308	5 / 15		3 / 11 [5]		O<C[4]	Meister, 2009
Wheat	England	2001-2005	FS	247 / 1,377	org + conv: 19		org + conv: 17	median org + conv: <5	O=C	Edwards, 2009b
Wheat	The Netherlands	2004	FS	22 / 17			1,300 / 360 [5]		O=C	Hoogenboom *et al.*, 2008
Wheat	Belgium	2002-2003	FS	51 / 42	27 / 45		10 / 39 [5]		O<C	Pussemier *et al.*, 2006
Wheat	Lithuania	2003	FS	11 /13	100 / 92	41 / 150	41 / 138		O<C	Bakutis *et al.*, 2006
Wheat	Germany	1999-2001	FT	40 / 40			4.4 / 28 [5]		O<C[4]	Schneweis *et al.*, 2005
Wheat	Germany	1998	FS	46 / 135	4 / 7	47 / 74		<20 / <20	O=C[4]	Döll *et al.*, 2002
Wheat	Germany	1991	FS	50 / 51	36 / 16	24 / 6			O>C[4]	Marx *et al.*, 1995
Oats	Poland	2009-2011	FS	34 / 24	24 / 53	1.7 / 7.6			O=C	Twaruzek *et al.*, 2013
Barley	Spain	2007-2008	FS	11 / 13	36 / 54	1.1 / 5.2	0.5 / 2.9	0.2 / 0.7	O=C	Ibanez-Vea *et al.*, 2012
Barley	Lithuania	2003	FS	11 / 13	82 / 100	56 / 211	46 / 211		O<C	Bakutis *et al.*, 2006
Rye	Poland	2009-2012	FS	52 / 24	46 / 71		2.1 / 9.8		O=C	Blajet-Kosicka *et al.*, 2014
Rye	Germany	2001-2007	FS	155 /294	0.6 / 5		<3 / <3 [5]		O<C[4]	Meister, 2009
Rye	Germany	1991	FS	50 / 50	10 / 18	51 / 4			O>C[4]	Marx *et al.*, 1995

[1] Empty cells imply data is not available.
[2] FS: field survey; BS: basket survey; FT: field trial.
[3] O: organic; C: conventional; O<C: organic significantly lower than conventional; O>C: organic significantly higher than conventional; O=C: no significant difference between organic and conventional.
[4] Statistical analysis not shown.
[5] Mean values of all samples are calculated means based on information in the papers (means of positive samples, yearly means or means of other subgrouped samples).

Nivalenol

The content of NIV in cereal grains from organic and conventional farming systems was compared in nine studies. Wheat was included in five, oats in four, barley in four, maize in one and rice in one of the studies (altogether 16 comparisons). The contamination level was low in grain from both farming systems, and most of the studies reported no differences in NIV content of grains from organic and conventional farming (Table 4).

In four studies, no differences in NIV content were reported in wheat from organic and conventional farming (Eltun, 1996; Griesshaber *et al.*, 2004; Mäder *et al.*, 2007; Malmauret *et al.*, 2002). In a field survey of wheat in Poland, lower NIV level was found in samples from organically (2.3 µg/kg) than in samples from conventionally produced grain, both with fungicide application (20 µg/kg) and without fungicide (24 µg/kg) (Perkowski *et al.*, 2007). In oats, most studies, including a comprehensive Norwegian farm survey from 2002-2004 (Bernhoft *et al.*, 2010), a survey from Poland (Kuzdralinsky *et al.*, 2013), and a field trial in Norway (Eltun, 1996), no differences in NIV levels in grains from the two farming systems were reported. Another survey from Poland reported on lower NIV level in organically (122 µg/kg) than in conventionally produced oats (166 µg/kg) (Twaruzek *et al.*, 2013). One comprehensive farm survey of barley from Norway (Bernhoft *et al.*, 2010), as

Table 4. Overview of studies comparing nivalenol content (percentage contaminated samples, mean of positive or all samples, and/or median concentration levels) in cereal grains from organic (Org) and conventional (Conv) farming systems.[1]

Cereal species	Country	Sampling years	Study type[2]	No of samples org/conv	% contam. samples org/conv	Mean (µg/kg) of positive org/conv	Mean (µg/kg) of all samples org/conv	Median (µg/kg) org/conv	Org vs conv[3]	Reference
Wheat	Switzerland	2000	FT				59 / 57		O=C	Mäder *et al.*, 2007
Wheat	Poland	2003	FS	12 / 15	17/ 53	Mean level 2.3 (org) / 20 (conv with fungicide)			O<C	Perkowski *et al.*, 2007
				12 / 5	17 / 80	Mean level 2.3 (org) / 24 (conv without fungicide)			O<C	
Wheat	Switzerland	1998-2000	FT	16 / 16	67	<10-136 / <10-177			O=C	Griesshaber *et al.*, 2004
Wheat	France		FS	11 / 11	91 / 0			10 / –	O=C	Malmauret *et al.*, 2002
Wheat	Norway	1992	FT				28 / 41		O=C	Eltun, 1996
Oats	Poland	2006-2008	FS	36 / 22	61 / 57	132 / 214		53 / 65	O=C	Kuzdralinsky *et al.*, 2013
Oats	Poland	2009-2011	FS	34 / 24	55 / 75		122 / 166	69 / 110	O<C	Twaruzek *et al.*, 2013
Oats	Norway	2002-2004	FS	101 / 101			50 / 34	<30 / <30	O=C	Bernhoft *et al.,* 2010
Oats	Norway	1992-1993	FT				119 / 105		O=C	Eltun, 1996
Barley	Norway	2002-2004	FS	108 / 108			<30 / <30	<30 / <30	O=C	Bernhoft *et al.*, 2010
Barley	France		FS	5 / 5	80 / 20			83 / 10	O=C	Malmauret *et al.*, 2002
Barley	Norway	1992	FT				180 / 120		O=C	Eltun, 1996
Cereals (rice, barley, maize)	Rep. of Korea	2009	BS	88 / 99	63 / 40 (all samples)	32 / 23 (all samples)		27 / 21 (all samples)	O>C (rice) O=C (barley) O=C (maize)	Ok *et al.*, 2011

[1] Empty cells imply data is not available.
[2] FS: field survey; BS: basket survey; FT: field trial.
[3] O: organic; C: Conventional; O<C: organic significantly lower than conventional; O>C: Organic significantly higher than conventional; O=C: no significant difference between organic and conventional.

well as one limited farm survey from France (Malmauret *et al.*, 2002), one field trial from Norway (Eltun, 1996) and one basket survey from South Korea (Ok *et al.*, 2011), reported no differences in NIV content between organically and conventionally produced barley. However, Ok *et al.* (2011) detected higher NIV levels in organically than in conventionally produced rice, but they found no differences in NIV in maize from the two farming systems.

Ochratoxin A

The concentrations of OTA in cereal grains and cereal-based products from organic and conventional production have been compared in 15 studies (Table 5). Some studies compared OTA content in more than one cereal species. Organically and conventionally produced wheat were included in 11 of the studies, oats in two, barley and rye in four studies each, and three studies were based on mixtures of cereals and cereal products, altogether 24 comparisons. Because only few studies presented documentation of the difference between OTA content in grains from the two farming systems, a number of studies lacking statistical analysis were included. Of studies with a statistical analysis, no significant difference in OTA content in samples from the two farming systems was found in four studies, while five reported higher OTA content in organically than in conventionally produced grains and products.

No significant difference in OTA concentrations in wheat from organic and conventional farming was reported in one

Table 5. Overview of studies comparing ochratoxin A content (percentage contaminated samples, mean of positive or all samples, and/or median concentration levels) in cereal grains and products from organic (Org) and conventional (Conv) farming.[1]

Cereal species	Country	Sampling years	Study type[2]	Number of samples org/conv	% contam. samples org/conv	Mean (µg/kg) of positive org/conv	Mean (µg/kg) of all samples org/conv	Median (µg/kg) org/conv	Org vs conv[3]	Reference
Wheat	Italy		FS	20 / 15			0.06 / 0.04		O=C	Rossi *et al.*, 2006
Wheat	Belgium	2002	FS	20 / 20	55 / 25		0.06 / 0.07	0.03 / 0.01	O=C	Pussemier *et al.*, 2006
Wheat	Lithuania	2003	FS	11 / 13	27 / 15	1.2 / 4.5	0.3 / 0.7		O=C[4]	Bakutis *et al.*, 2006
Wheat	Poland	1997	FS	39 / 32	8 / 0	0.8 / <LOD[5]			O>C[4]	Czerwiecki *et al.*, 2002a
Wheat	Poland	1998	FS	34 / 37	24 / 49	1.2 / 267			O<C[4]	Czerwiecki *et al.*, 2002b
Wheat	Denmark	1992-1999	FS	14 / 405			0.3 / 0.3		O=C[4]	Jørgensen and Jacobsen, 2002
Wheat	Denmark	1986-1992	FS	73 / 402			1.2 / 0.7		O=C[4]	Jørgensen *et al.*, 1996
Wheat bran	Spain	2012	BS	11 / 26	45 / 15	1.4 / 0.6			O>C	Vidal *et al.*, 2013
Wheat bran	Denmark	1986-1992	FS	22 / 120			0.6 / 0.8	0.3 / 0.2	O=C[4]	Jørgensen *et al.*, 1996
Whole wheat flour	Croatia	2008-2009	BS	12 / 12	100 / 100		1.5 / 2.9		O=C[4]	Vrcek *et al.*, 2014
Wholemeal wheat flour	Belgium	2002	BS	40 / 40	100 / 95		0.5 / 0.2	0.1 / 0.4	O=C	Pussemier *et al.*, 2006
Oats	Poland	2006-2008	FS	36 / 22	64 / 83	3.6 / 3.2		3.3 / 3.1	O=C[4]	Kuzdralinski *et al.*, 2013
Oats	Denmark	1986-1992	FS	17 / 50			0.3 / 0.5		O=C[4]	Jørgensen *et al.*, 1996
Barley	Denmark	1986-1992	FS	20 / 41			1.0 / 0.9		O=C[4]	Jørgensen *et al.*, 1996
Barley	Poland	1997	FS	40 / 26	8 / 4	26 / 0.3			O>C[4]	Czerwiecki *et al.*, 2002a
Barley	Poland	1998	FS	17 / 36	12 / 6	18.4 / 5.5			O>C[4]	Czerwiecki *et al.*, 2002b
Barley	Spain	2007-2008	FS	11 / 13	64 / 38	0.6 / 0.1	0.4 / 0.02	0.1 / 0.01	O>C	Ibanez-Vea *et al.*, 2012
Rye	Denmark	1992-1999	FS	17 / 405			3.9 / 0.9		O>C	Jørgensen and Jacobsen, 2002
Rye	Denmark	1986-1992	FS	91 / 503			5.4 / 1.2	0.4 / Nd[6]	O>C	Jørgensen *et al.*, 1996
Rye	Poland	1997	FS	48 / 52	38 / 6	3.2 / 1.4			O>C[4]	Czerwiecki *et al.*, 2002a
Rye	Poland	1998	FS	46 / 37	11 / 11	14.5 / 7			O>C[4]	Czerwiecki *et al.*, 2002b
Mixed (wheat, maize, oats, barley, rice, rye, spelt)	Spain, Portugal	2005	BS	41 / 42	32 /12		1.6 / 0.1		O>C	Juan *et al.*, 2008
Breakfast cereals	USA	2012-2013	BS	56 / 88	54 / 51	1.2 / 0.8		0.4 / 0.2	O>C[4]	Nguyen and Ryu., 2014
Cereal products	Italy	2001-2002	BS	96 / 77					O=C	Biffi *et al.*, 2004

[1] Empty cells imply data is not available.

[2] FS: field survey; BS: basket survey; FT: field trial.

[3] O: organic; C: conventional; O<C: organic significantly lower than conventional; O>C: organic significantly higher than conventional; O=C: no significant difference between organic and conventional.

[4] Statistical analysis not shown.

[5] LOD: limit of detection.

[6] Nd: not detected/determined.

study from Italy (Rossi *et al.*, 2006) and in one study from Belgium (Pussemier *et al.*, 2006). Four studies indicated similar OTA content in wheat from the two farming systems (Bakutis *et al.*, 2006; Jørgensen and Jacobsen, 2002; Jørgensen *et al.*, 1996; Vrcek *et al.*, 2014). From Poland, considerably lower mean OTA level was reported in organically (1.2 μg/kg) than in conventionally (267 μg/kg) produced wheat in 1998 (Czerwiecki *et al.*, 2002b), whereas another study from the previous year indicated higher OTA levels in organically (0.8 μg/kg) than in conventionally (< limit of detection) grown wheat (Czerwiecki *et al.*, 2002a). One basket survey in Spain detected significantly higher OTA concentration in bran from organically grown wheat compared to conventionally grown (Vidal *et al.*, 2013). Two studies of oats, one from Poland (Kuzdralinski *et al.*, 2013) and one from Denmark (Jørgensen *et al.*, 1996) and one Danish barley study (Jørgensen *et al.*, 1996), indicated no differences in OTA concentrations in grain form organic and conventional production. Two other studies indicated higher OTA levels in samples from organically than from conventionally grown barley (Czerwiecki *et al.*, 2002a,b). One Spanish study detected significantly higher OTA concentrations in organically than in conventionally grown barley (Ibáñez-Vea *et al.*, 2012). Four studies, two from Denmark (Jørgensen and Jacobsen, 2002; Jørgensen *et al.*, 1996), and two from Poland (Czerwiecki *et al.*, 2002a,b) indicated higher OTA concentrations in organically than in conventionally grown rye. An Italian study of whole flour and other cereal products found no significant difference in OTA content between samples from conventional and organic farming (Biffi *et al.*, 2004). In a study of mixed cereals and cereal products from Spain and Portugal, significantly higher OTA levels were detected in grain from organic than from conventional farming (Juan *et al.*, 2008). A study in United States indicated higher OTA concentrations in organically than in conventionally produced breakfast cereals (oats, maize, wheat, rice) (Nguyen and Ryu, 2014).

Most studies found low levels of OTA, and often a large number of samples below the limit of detection was reported, both in grains from organic and from conventional farming. The available data indicates that there is no difference in OTA levels in grain from the two farming methods, although a few studies showed higher content in organically than in conventionally produced cereals. In a systematic review comparing organic and conventional foods, no statistically significant difference was found between the two production systems, neither in incidence nor in mean OTA concentrations (Smith-Spangler *et al.*, 2012).

OTA is mainly produced in food items that are not sufficiently dry, and in cereal grains moisture content below 14-14.5% is considered safe to prevent OTA production (Magan and Aldred, 2007). The reported difference in OTA concentrations between organic and conventional cereals is likely to be more related to drying and storage conditions than to agricultural practise. It has been suggested that a greater amount of impurities and/or less uniform maturity may cause organically produced grain to be more susceptible to growth of fungi than conventionally produced (Jørgensen and Jacobsen, 2002). This may imply that correct handling and drying are even more important for organically than for conventionally produced cereals.

Fumonisins

There are few studies published on the effects of organic and conventional farming systems on fumonisin content of maize (Table 6), which is the most frequently fumonisin-contaminated crop (Marasas, 1995). Only members of the fumonisin B-series occur in biologically important quantities, and fumonisin B_1 (FB_1) and fumonisin B_2 (FB_2) are the most abundant in maize.

In Spain, De Galarreta *et al.* (2015) evaluated nine maize varieties in field experiments at four locations in Spain during two years. The levels of fumonisin contamination in samples from organic plots were not significantly different from samples from conventional plots. However, the levels of fumonisins were significantly different between locations. In another Spanish study, only low levels of fumonisins were detected in maize from the years 2001 to 2003, and there was no significant difference in fumonisin concentration in samples from the two farming systems (Ariño *et al.*, 2007). In a survey in Italy the median FB_1 concentrations were not significantly different between organically and conventionally produced maize-based foodstuff; it was lower in organically than in conventionally produced wheat-based food-stuff, and higher in organically than in conventionally produced rice-based food-stuff (Cirillo *et al.*, 2003). The median FB_2 concentrations were not significantly different between organically and conventionally produced wheat-based foodstuff; it was lower in organically than in conventionally produced rice-based food-stuff, and higher in organically than in conventionally produced maize-based food-stuff (Cirillo *et al.*, 2003). The limited number of comparative studies published does not indicate that there is any effect of farming systems on fumonisin content of cereals.

Other mycotoxins in cereals

The *Fusarium* mycotoxins diacetoxyscirpenol (DAS), monoacetoxyscirpenol (MAS), 3-acetyldeoxynivalenol (3-ADON) and moniliformin (MON) have been analysed in a few studies comparing mycotoxin content in cereal grains from organic and conventional farming. A Polish study of oats during 2006-2008 reported significantly higher concentrations of DAS in samples from conventional (median 456 μg/kg) than in samples from organic farming (median

Table 6. Overview of studies comparing fumonisin content (percentage contaminated samples, mean of positive or all samples, and/or median concentration levels) in maize, wheat and rice from organic (org) and conventional (conv) farming.[1]

Cereal species	Country	Sampling years	Study type[2]	No of samples org/conv	% contam. samples org/conv	Mean (µg/kg) of all samples org/conv	Median (µg/kg) org/conv	Org vs conv[3]	Reference
Maize	Spain	2010-2011	FT	108 / 108		210 / 520 Galicia 1,420 / 1,480 Basque		O=C O=C	De Galarreta *et al.*, 2015
Maize	Spain	2001-2003	FS	30 / 30	10 / 13 7 / 10	35 / 43 FB_1 19 / 22 FB_2		O=C O=C	Ariño *et al.*, 2007
Maize and products	Italy	2002	BS	27 / 27	44 / 30 FB_1 32 / 22 FB_2		185 / 345 FB_1 120 / 20 FB_2	O=C O>C	Cirillo *et al.*, 2003
Wheat and products	Italy	2002	BS	36 / 44	11 / 9 28/ 45		25 / 97 FB_1 210 / 90 FB_2	O<C O=C	Cirillo *et al.*, 2003
Rice and products	Italy	2002	BS	11 / 13	36 / 23 45 / 38		145 / 30 FB_1 150 / 205 FB_2	O>C O<C	Cirillo *et al.*, 2003

[1] Empty cells imply data is not available. FB_1: fumonisin B_1; FB_2: fumonisin B_2.
[2] FS: field survey; BS: basket survey; FT: field trial.
[3] O: organic; C: conventional; O<C: organic significantly lower than conventional; O>C: organic significantly higher than conventional; O=C: no significant difference between organic and conventional.

79 µg/kg) (Kuzdraliński *et al.*, 2013). In another Polish study (2009-2011) no significant differences in concentrations in oats from organic and conventional farming were detected for DAS, MAS or 3-ADON (Twarużek *et al.*, 2013). Bernhoft *et al.* (2010) reported lower MON levels in organically than in conventionally produced wheat in one year, but not in samples from the two other years studied. Aflatoxins are a group of toxic secondary metabolites produced primarily by species of the fungal genus *Aspergillus*. Kuzdralinsky *et al.* (2013) reported lower aflatoxin levels in oat samples from organic farming one year, however, no differences were found between samples from organic and conventional farming, when all samples were considered together. No significant differences in aflatoxins were found in organically and conventionally produced barley from Spain (Ibáñez-Vea *et al.*, 2012). In Lithuania, small amounts of aflatoxin were found in samples of wheat from organic farms, but the mycotoxin was not detected in conventionally grown wheat (Bakutis *et al.*, 2006). In a German study of ergot alkaloids produced by *Claviceps pupurea* in rye grains, Lauber *et al.* (2005) found lower concentrations of alkaloids in organically grown rye compared to conventionally grown rye. In another German study lower alkaloid content in sclerotia from *C. purpurea* was observed in organically than in conventionally produced rye (Lücke *et al.*, 2003). For the mycotoxins mentioned in this section the number of studies is far too low to allow any conclusion on the comparison of contamination levels in grains from organic versus conventional production.

3. Mycotoxins in other crops

Patulin

Patulin producing fungi can occur in a variety of fruits and vegetables, however, contaminated apples, apple juice and other apple products made from mouldy fruit are considered the major source of human exposure to PAT (Barkai-Golan and Paster, 2008; Jackson and Al-Taher, 2008). Ten surveys (nine basket surveys and one field survey), comparing the PAT content in organically and conventionally produced apples and apple products, and one of tomato and tomato products, were assessed (Table 7). As one of these studies compared apples and apple juice separately, there were altogether 12 comparisons. Four studies reported higher PAT frequencies and/or contamination levels in samples of organically than in conventionally produced apple juice and fruit juice. The other studies showed no differences in PAT content in products from the two farming systems. In Europe, maximum PAT levels of 50 µg/l in apple juice, 25 µg/kg in solid apple products and 10 µg/kg in apple-based products intended for infants and young children, have been established (EC, 2006).

In the assessed studies, the PAT concentrations were mostly below the established legal limits. Low levels of PAT were detected in apples in Italy, with no difference in contamination between samples from organic and conventional production (Piemontese *et al.*, 2005). Three other Italian surveys reported no difference in the mean

Table 7. Overview of studies comparing patulin content (percentage contaminated samples, mean of positive or all samples, and/or median concentration levels) in apple, apple based products and in tomato, from organic (Org) and conventional (Conv) farming systems.[1]

Crop	Country	Sampling years	Study type[2]	No of samples org/conv	% contam. samples org/conv	Mean (µg/kg) of positive org/conv	Mean (µg/kg) of all samples org/conv	Median (µg/kg) org/conv	Org vs conv[3]	Reference
Apple	Italy	2003-2004	BS	9 / 13	33 / 54		11.3/11.1	0.07/0.45	O=C	Piemontese *et al.*, 2005
Apple	France		FS	6 / 6	33 / 0	Level ranges	5-1,250 / <5	5/<5	O=C	Malmauret *et al.*, 2002
Apple (and apple juice)	Portugal		BS	13 / 8	54 / 50	Level ranges: Nd[4]-1,210 org / Nd[4]-71 conv			O=C	Cunha *et al.*, 2014
Apple juice	Spain		BS	24	73 / 15		9.3/1.4		O>C	Pique *et al.*, 2013
Apple juice	Italy		BS	8 / 14	38 / 64	9.8 / 2.5		6.4/2.1	O=C	Versari *et al.*, 2007
Apple juice	Italy	2005	BS	21 / 32	29 / 59	9.9 / 9.0		0.8/2.7	O=C	Spadaro *et al.*, 2007
Apple juice	Belgium		BS	65 / 90	12 / 13	43 / 10.2	8.8/4.1		O>C	Baert *et al.*, 2006
Apple juice and products	Italy		BS	17 / 23		28.3 / 24.8			O=C	Ritieni *et al.*, 2003
Apple/fruit juice	Italy	2003-2004	BS	69 / 100	45 / 26		4.8/1.2	0.07/0.07	O>C	Piemontese *et al.*, 2005
Apple/fruit juice	Italy		BS	21 / 21		7.7 / 1.0			O>C	Beretta *et al.*, 2000
Apple-based foods/juice	Portugal	2007-2009	BS	35 / 109	20 / 24	Level ranges: LOD[5]-9.2 org / LOD[5]-42 conv			O=C	Barreira *et al.*, 2010
Tomato (and products)	Portugal		BS	4 / 28	75 / 43	Level ranges: Nd[4]-21 org / Nd[4]-48 conv			O=C	Cunha *et al.*, 2014

[1] Empty cells imply data is not available.
[2] FS: field survey; BS: basket survey; FT: field trial.
[3] O: organic; C: conventional; O<C: organic significantly lower than conventional; O>C: organic significantly higher than conventional; O=C: no significant difference between organic and conventional.
[4] Nd: not detected/determined.
[5] LOD: limit of detection.

PAT contents in apple juice and apple products from the two farming systems (Ritieni, 2003; Spadaro *et al.*, 2007; Versari *et al.*, 2007). In two surveys of apples and apple-based products in Portugal no difference in PAT levels between samples from organic and conventional production was detected (Barreira *et al.*, 2010; Cunha *et al.*, 2014), although one rotten sample of one variety from organic production had significantly higher PAT content than the conventionally produced counterpart (1,210 µg/kg and 71 µg/kg, respectively) in the study by Cunha *et al.* (2014). In a limited French farm survey no difference in PAT content was detected between organically and conventionally produced apples (Malmauret *et al.*, 2002). Two surveys from Italy found significantly higher PAT levels in apple and fruit juice from organic farming than in samples from conventional farming (Berretta *et al.*, 2000; Piemontese *et al.*, 2005). Also, a survey from Belgium reported significantly higher mean PAT level in organically (8.8 µg/kg) than in conventionally (4.1 µg/kg) produced apple juice (Baert *et al.*, 2006). In addition to reporting their own results from Spain, which showed higher PAT content in samples from organic than from conventional farming, Pique *et al.* (2013) presented an update of the PAT occurrence and a risk assessment of contamination in conventional and organic apple juices in nine European countries. They concluded that the incidence and the levels of PAT were, in general, higher in organically than in conventionally grown apple products. In organically produced tomatoes, no significant difference in PAT contamination from the two farming systems was found (Cunha *et al.*, 2014).

Production of PAT in apples is sensitive to harvesting techniques, storage conditions and other processing practices, which are not relevant to the farming system per se. Despite PAT production is believed to occur mainly post-harvest, also factors during the growing season may influence fungal infection and mycotoxin production in apples. The higher PAT levels in organically produced apples detected in some studies may be due to more efficient disease control in conventional orchards. Post-harvest decay can be reduced by pre-harvest fungicide applications, and thereby reduce the mycotoxin producing fungi in fruits

(Jackson and Al-Taher, 2008; Sugar and Spotts, 1995). The results also indicate that it is important to remove decayed and damaged fruit during juice processing in both production systems. It was shown that, in rotten apples, the PAT spreads to unaffected parts of the fruit (Beretta *et al.*, 2000).

Other mycotoxins

In a study on occurrence of *Alternaria* toxins in flax and pea in the Czech Republic in 2002-2003, higher concentrations were found in samples of organically than in conventionally produced flax from one year (Kralova *et al.*, 2006). No *Alternaria* toxins were detected in pea samples. In Denmark, Jensen *et al.* (2013a) analysed organically and conventionally grown strawberries for a number of mycotoxins, including fumonisins and OTA. No toxins were detected in mature berries, including samples of low quality berries, from either of the cultivation systems.

4. Conclusions

The available data show that the ranking of organic versus conventional farming systems due to mycotoxin contents in raw material is not consistent. It cannot be concluded that any of the two farming systems increases the risk of mycotoxin contamination. Some studies indicated that other factors, like weather, cropping year, locations, crop rotation, tillage practice and choice of cultivars may have more influence on the mycotoxin levels than the type of farming. Despite no use of fungicides, an organic system appears generally able to maintain mycotoxin contamination at low levels. Contamination of cereals with mycotoxins is widespread in both organic and conventional grains, but mostly at low levels.

For the most commonly occurring mycotoxin in cereals, DON, most studies reported no difference in the content of grain from the two farming systems. The majority of the remaining studies reported on lower DON levels in organically than in conventionally produced cereals. For studies comparing T-2 and HT-2, lower levels were detected in organically than in conventionally grown cereals in half of the comparisons, mainly in oats. Most studies on ZEA reported no differences between the farming systems, or lower concentrations in organically produced grain. For the other mycotoxins in cereals, most of the studies reported no differences in samples from organic and conventional farming. Some studies showed higher PAT contamination in organically than in conventionally grown apple and apple products. However, with few exceptions, low PAT levels were reported, often below the legal limits for PAT in apple juice and apple-based products.

A number of uncertainties influence the comparisons of mycotoxin content in organic and conventional farming. More systematic comparisons performed in field trials and surveys under scientifically controlled conditions are needed to clarify if there are differences in the risk of mycotoxin contaminations between organically and conventionally produced crops.

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