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European case study on seed treatments and seed-borne disease control using seed treatments

by

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CONTENTS

1. ABSTRACT

Seed-borne diseases are important problems in many crops in European agriculture. In cereals, serious diseases like bunt (*Tilletia tritici*), loose smut (*Ustilago nuda*), net blotch (*Pyrenophora teres*) and leaf stripe (*Pyrenophora graminea*) occur regularly but are kept at a relatively low level because of systematic and intensive use of seed treatments. In conventional agricultural systems, seed-borne diseases could develop as serious problems if programmes with reduced pesticide inputs are initiated because of EU legislation. In organic farming, bunt (*Tilletia tritici*), for example, could be a major problem in the production of seeds. Due to the reliance on effective chemical methods, few developments have been made in the non-chemical area of seed-borne disease control. Research into alternative non-chemical seed treatments for use in organic systems has indicated a range of possible approaches, but to date most of these do not give sufficiently high levels of control to offer credible alternatives to existing chemical control methods. In some countries the use of resistant varieties is an important factor in an integrated strategy to control seed-borne diseases. There are resistance genes available but often we do not know their occurrence in modern varieties. It is clear from the data presented here that there is considerable variation amongst the countries surveyed of the perceived threats posed by individual seed-borne diseases. Perhaps as a consequence, there is also a wide range of thresholds that are applied in order to control the diseases. Some of this variation may be explicable in that there will be considerable variation in the amount of spring and winter cropping in these countries and this will affect the occurrence and severity of some seed-borne diseases. Some of the variation in thresholds and perceived threat from seed-borne diseases is related to climatic conditions. In most countries there is little interpretation of thresholds, i.e. they are applied strictly. In the UK there is more of a tendency for advisers to use the advisory thresholds but adapt them depending on individual farm circumstances. Why this is the case is not obvious, but is perhaps linked to the predominance of independent crop advisers in the UK, whereas in most EU countries there are state or government advisers who may apply thresholds more strictly. The use of farm-saved seed is common in many countries with typically 40-50% of crops grown from non-certified seed. It is clear that there is no agreement on European standardisation of thresholds or in the approaches to the use of seed treatments. This is in contrast to the high degree of standardisation of seed testing methodologies that are employed in EU countries. This has been achieved via the International Seed Testing Association (ISTA) which has a clear role in seed testing procedures. ISTA has developed and published standard procedures in the field of seed testing and has member laboratories in over 70 countries. It produces internationally agreed rules for seed sampling and testing, accrediting laboratories, promoting research, and providing international seed analysis certificates, training and dissemination of knowledge in seed science and technology to facilitate seed-trading nationally and internationally. It is possible that in the future it could have an influence in the area of seed treatment thresholds.

2. EUROPEAN CASE STUDY ON SEED TREATMENTS AND SEED-BORNE DISEASE CONTROL USING SEED TREATMENTS

2.1. Introduction

Seed-borne pathogens are among the most important causes of disease problems and, therefore, measures aimed at a reduction of these pathogens at the seed level are of crucial importance. The current use of chemical seed treatments is characterised by a ‘no risk’ attitude by the users that tends to lead to a higher than necessary use of fungicides. Studies have shown that chemical seed treatments can be reduced or even omitted if seeds are free of pathogens or if information on infection levels and tools for optimised use of seed treatments are available to support the decision-making. Restricting and better targeting of fungicide seed treatments will also contribute to the avoidance of the currently widespread problems with fungicide resistance in cereal pathogens. The objective of the seed treatment case study is to investigate integrated seed treatment strategies for management of diseases which will improve the sustainability of crop production. The case study focused on the most important problems in cereals. The data presented here is based on inputs from ISTA members and current knowledge within the ENDURE network.

ENDURE, (European Network for the Durable Exploitation of Crop Protection Strategies), is a network of excellence funded by the European Union under the Framework 6 programme. A primary aim of ENDURE is to establish a European network of expertise and knowledge. This has already been achieved during 2007/2008. Its main focus was: “Safer and environmentally friendly production methods and technologies and healthier food stuffs”. This was to be largely achieved through reducing the use of plant protection products. The participants in the ENDURE project have provided some of the information in this HGCA-funded project

ENDURE Participants	Country
• INRA (ENDURE Coordinator)	FR
• Association de Coordination Technique Agricole ACTA	FR
• CIRAD	FR
• INRA Transfert IT	FR
• International Biocontrol Manufacturers’ Association IBMA	INT
• Consiglio Nazionale delle Ricerche CNR	IT
• Scuola Superiore di Studi Universitari e di Perfezionamento SSSUP	IT
• Biologische Bundesanstalt für Land- und Forstwirtschaft BBA	DE
• Rothamsted Research RRES	UK
• Danish Institute of Agricultural Sciences DIAS	DK

• Danish Agricultural Advisory Service DAAS	DK
• Agroscope Swiss Federal Research Station AGROS	CH
• Plant Breeding and Acclimatization Institute IHAR	PL
• Szent István University SZIE	HU
• Universitat de Lleida UdL	ES
• Plant Research International PRI Wageningen	NL

This report investigates the approaches taken in other European countries towards seed treatments and thresholds. Information was gathered via ENDURE collaboration and via an email questionnaire to ISTA members.

The International Seed Testing Association (ISTA) plays a clear role in seed testing procedures. ISTA was founded in 1924, with the aim of developing and publishing standard procedures in the field of seed testing and has member laboratories in over 70 countries. ISTA produces internationally agreed rules for seed sampling and testing, accrediting laboratories, promoting research, and providing international seed analysis certificates, training and dissemination of knowledge in seed science and technology to facilitate seed-trading nationally and internationally. However, crucially, it is not involved in setting or promoting the use of thresholds for fungicidal treatment of seeds.

2.1.1. Objectives

- Determine expertise in seed health and seed treatments (insecticides and fungicides) across Europe. Identify both individuals and institutes with specific expertise.
- Compare alternative strategies and approaches to the control of seed-borne pathogens in cereals and oilseed rape.
- Determine the range of diagnostic methods currently used and proposed.
- Evaluate and compare current thresholds used to determine the need for seed treatment in Europe.
- Explore innovative crop protection systems for seed treatment for the control of seed-borne diseases.

2.2. Seed treatment and seed testing – background

2.2.1. Seed Treatment

Seed treatments have been used in cereals for centuries, mainly as a means of controlling seed-borne diseases that cannot be controlled later in the crop's development. Diseases such as bunt of wheat (*Tilletia tritici*) and leaf stripe of barley (*Pyrenophora graminea*) have been well controlled since the introduction of organomercury in the 1930's when seed-borne diseases like bunt and leaf stripe were common. Modern seed treatment technology now offers very safe and environmentally friendly alternatives to mercury. As a consequence of the availability of safe and cost-effective seed treatments, the UK farming industry embraced the technology and seed treatments became almost universally used by UK farmers. Compared with the cost of foliar fungicides, fungicidal seed treatments have always been relatively inexpensive. However, with increasingly sophisticated seed treatments available, the cost of seed treatment became significant and some farmers began to question the need for seed treatment in all cases. To enable farmers and advisers to make rational decisions on the need for seed treatment, thresholds for seed treatment were devised.

The use of seed treatments to control seed-borne diseases again came into question following a survey of seed-borne diseases in commercial and farm-saved seed (Cockerell and Rennie, 1996) which showed that between 10% - 80% of winter wheat, and 60% - 90% of barley seed stocks, carried either no disease or had disease levels below the threshold levels of the major seed-borne pathogens.

The UK Pesticide usage survey report (Garthwaite *et al.*, 2006) showed that on average, wheat crops received three foliar fungicide applications, comprising a total of five products and eight active substances. Approximately 36% of all seed sown in England & Wales was farm-saved from the previous crop. Other cereal crops are very different, particularly in the amount sown untreated. The survey reported that almost eight percent of wheat seed was sown untreated, three percent of the winter barley seed remained untreated, approximately 14% of spring barley was sown using untreated seed, approximately 25% of the area of oats was sown using untreated seed and over 40% of triticale was sown untreated (Table 1).

Table 1. Treated areas of cereals in Great Britain 2006 (spray hectares)

	Wheat	**W. barley**	**S. barley**	**Oats**	**Rye**	**Triticale**
Foliar fungicides	8,690,342	1,102,963	1,183,750	209,584	8,546	8,862
Seed treatments	1,849,397	372,296	419,823	89,254	6,351	1,875
Total crop area	1,824,181	382,941	475,324	119,607	6,712	12,710
% seed treated	92.1	96.7	86.0	74.7	94.6	17.2
% untreated (seed)	3.3	0.9	2.8	14.0	-	43.0

2.2.2. Seed testing – Wheat and Barley

In the UK considerable detail is available to growers on both advisory standards and certification standards. Examples of those standards available to UK growers of wheat and barley are given in Tables 2 and 3. It is generally not recommended to sow untreated seed if it has not been tested for seed-borne diseases. The most important seed-borne diseases of UK wheat are the seedling blights caused by *Microdochium nivale* and *Phaeosphaeria nodorum*, and bunt (*Tilletia tritici*). Other statutory diseases such as ergot (*Claviceps purpurea*) and loose smut (*Ustilago nuda*) are included in certification standards and can be tested for.

For seed testing to be worthwhile, the final result must provide information that relates to the field performance of the crop. Many of the currently used thresholds have been developed from experimental work carried out over many years. However, the experimental work has been primarily carried out on wheat and barley. Current seed standards (as given in the individual Cereal Seeds Marketing Regulations for all UK countries) and UK advisory thresholds are given in table 2.

2.2.3. Seed Testing – Other cereals

Seed testing and seed treatment thresholds in the UK are much less well defined than for wheat and barley. Other European countries adopt thresholds for advisory purposes. These are shown in section 2.5.

2.2.4. Seed-borne Disease Thresholds

Apart from the two statutory seed-borne diseases, ergot (*Claviceps purpurea*) and loose smut (*Ustilago nuda*), most seed-borne diseases are dealt with using advisory thresholds. These are guidelines which can be interpreted depending on crop, field and seasonal conditions. These are discussed in more detail in section 4.

Table 2. Tests available for seed-borne pathogens of wheat and the current seed standards or advisory thresholds.

Seed-borne disease / pathogen	Test method	How result reported	Standard or Advisory threshold
Bunt *Tilletia tritici*	**Wash/filtration method.** Spores of *Tilletia tritici* are washed from the seed surface in a mild solution of detergent. The solution is passed through a filter of a suitable pore size to trap any *T. tritici* spores present. The filters are then examined microscopically.	Number of spores per seed	Advisory: 1 spore/seed above which a seed treatment should be used.
Bunt *Tilletia tritici*	**Molecular test.** Spores of *Tilletia tritici* are washed from the seed surface in a mild solution of detergent. DNA is extracted from solution. The amount of *T. tritici* DNA present is measured using real-time PCR. The amount of DNA present is then converted to spores per seed using a calibration curve.	Either >1 spore per seed or < 1 spore per seed.	Advisory: 1 spore/seed above which a seed treatment should be used.
Microdochium Seedling Blight	**Agar Plate Test** Individual seeds are placed on to potato dextrose agar in petri dishes. If *M. nivale* is present the fungus grows out from the seed into the agar. The number of infected seeds in 200 seeds is counted.	% infection	Advisory: 10% above which there is a benefit to use seed treatment.
Microdochium Seedling Blight	**Molecular test.** Seeds are crushed and then soaked to release fungal DNA. The amount of *M. nivale* DNA present is measured using real-time PCR. The amount of DNA present is then converted to a percentage seed infection using a calibration curve.	Either >10% or <10% infection	Advisory: 10% above which there is a cost benefit to use seed treatment.
Septoria seedling blight	**Agar plate test** As for *M. nivale* seedling blight	% infection	Advisory: 10% threshold
Fusarium graminearum	**Agar plate test** As for *M. nivale* seedling blight	% infection	Advisory: 10% threshold.

Ergot *Claviceps purpurea*	**Search** A 500g (Certified seed minimum standard and advisory) or 1000g sample (certified seed higher standard) is examined for sclerotia of *Claviceps purpurea*.	Number of pieces found in either 500g or 1000g	Advisory / Min Standard: 3 pieces of ergot in 500g. Standard: For certified seed of HVS 1 piece of ergot in 1000g
Loose smut *Ustilago nuda* f.sp. *tritici*	**Embryo extraction method**	% infection in 1000 embryos (advisory) or 2000 embryos (certification)	Advisory / Min Standard: 0.5% Standard: 0.2% Certified seed HVS

Table 3. Tests available for seed-borne pathogens of barley and the current seed standards or advisory thresholds.

Seed-borne disease /Pathogen	**Test method**	**How result reported**	**Standard or Advisory threshold**
Loose smut. *Ustilago nuda* f.sp. *hordei*	Embryo extraction	% infection in 1000 (advisory) or 2000 (certification)	Advisory/ Min. Standard: Max infection: 0.5% Standard: Max. infection: 0.2% HVS
Leaf stripe *Pyrenophora graminea*	Agar plate	% infection	Advisory: Treat if over 2%
	Molecular	Presence or Absence	Advisory: Treat if present
Net blotch *Pyrenophora teres* f.sp. *teres*	Agar plate	% infection	Advisory: Treat if over 10%
	Molecular	% infection	Advisory: Treat if over 10%
Ergot *Claviceps purpurea*	Visual count	Number of pieces: in 500g or 1000g	Advisory / Min.Standard 3 pieces/500g Standard 1 piece/1000g – HVS
Covered smut *Ustilago hordei*	Seed wash	Spores/seed	Advisory: Treat if present
Microdochium nivale	Agar plate	% infection	Advisory: Treat if over 30%
Fusarium graminearum	Agar plate	% infection	Advisory: Treat if over 10%
Cochliobolus sativus	Agar plate	% infection	Advisory: Treat if over 30%

2.3. Seed certification

There are several organisations and directives involved in seed health and seed testing. The three main areas/institutions involved are:

European Commission Directives - require that seed of the main agricultural, horticultural and vegetable species must be officially certified before marketing. The directives define specific standards under which seed must be marketed. Seed may not be marketed unless it is a species/variety on a National List or the EC Common Catalogue.

Organisation for Economic Co-operation and Development - operates schemes for the varietal certification of seed to encourage the use of seed of consistently high quality in participating countries. The Schemes are open to all Members of the Organisation, as well as to other States being members of the United Nations Organisation or its Specialised Agencies.

International Seed Testing Association - is responsible for the development of standard procedures for sampling and testing seeds and to promote uniform application of these procedures for evaluation of seeds moving in international trade. The secondary purpose of the Association is to actively promote research in all areas of seed science and technology.

UK certifying authorities:

- Fera - England and Wales
- Scottish Government - Scotland
- DARD – Northern Ireland

In the UK the sale of cereal seeds is controlled through seeds regulations and only certified seed may be marketed. Certified seed must meet minimum quality standards. England, Northern Ireland, Scotland and Wales all have their own seeds marketing regulations that are part of an EU-wide framework which ensures that seeds meet the same quality standards.

All cereal seeds subject to the regulations have to be officially certified and can only be sold in labelled containers which preserve the integrity of the seed inside. The Certifying Authority for England and Wales is the Department for Environment, Fisheries and Rural Affairs (DEFRA). In Scotland the Certifying Authority is SASA (Science and Advice for Scottish Agriculture) and in Northern Ireland, the Department of Agriculture and Rural Development (DARD). The certification process requires that the seed be tested to ensure that it meets all the standards that apply to it. Some of these tests are by crop inspection and others are done on the harvested seed. Certified seed is quality assured and must meet minimum quality standards. However, the two main seed-borne diseases of wheat, seedling blight (*Microdochium nivale*) and bunt (*Tilletia tritici*), are not included in the scheme, so seed is often routinely treated with fungicide seed treatments to protect against these two diseases.

All Cereal Seeds Regulations within the UK adopt the EU standard for the presence of ergot sclerotia in Minimum Standard seed samples (table 2), and they also include a Higher Voluntary Standard (HVS). For loose smut and other seed-borne pathogens of cereals there is a general requirement in the EU Directive for seed health, which states: "*Harmful organisms which reduce the usefulness of the seed, in particular Ustilagineae (smuts), shall be at the lowest possible level.*"

However, the EU Directive does not lay down standards for any individual seed-borne disease. Cereal Seeds Regulations within the UK go further than the EU Directives, in that maximum levels of infection are also prescribed for loose smut (*Ustilago nuda*). The certification procedure does not, however, require routine testing of every seed lot.

Table 4. Maximum permitted loose smut infection and ergot contamination in certified wheat seed produced in the UK.

	Infection with loose smut (%)	
	Minimum Standard (MS)	Higher Voluntary Standard (HVS)
Basic	0.5	0.1
C1 and C2	0.5	0.2

	Maximum pieces of ergot in 1000g	
	Minimum Standard (MS)	Higher Voluntary Standard (HVS)
Basic seed	2	0
C1 and C2	6	1

2.4. Application of seed-borne disease thresholds

Apart from the certification standards for ergot and loose smut, published seed-borne disease thresholds are advisory i.e. they can be used for guidance. Individual farmers and advisers may apply the thresholds in different ways depending on individual farm or field circumstances.

2.4.1. Bunt (*Tilletia tritici*)

The UK advisory limit for seed treatment is one spore per seed, equivalent to 20 spores per gram of seed. Spore contamination of around 100 spores per seed is considered high, and advice would normally be to discard the seed. As this disease is common throughout Europe, it might be expected that similar thresholds would apply wherever the disease is found. However, thresholds range from zero to 10 spores/seed in conventional crops and up to 50 spores/seed in organic crops. One might assume that thresholds might differ depending on environmental conditions such as temperature and soil moisture. It is known that disease expression is controlled by a range of environmental factors (Gaudet *et al*., 1989). The severity of bunt infection has been correlated with variability in soil moisture and temperature during the period of germination of winter wheat. Hungerford (1922) showed a strong positive relationship between the percentage of bunt-infected wheat plants and soil moisture during the period of seed germination. There was no infection at soil moisture levels of less than 10%.

From these and other similar experiments, the optimum soil moisture level for germination of bunt spores is thought to be 13-14 %. Winter wheat seed will germinate at soil moisture levels of 10 % - consequently, sowing wheat into relatively dry soil is likely to reduce the level of bunt infection.

Soil temperature can also affect infection levels. Johnsson (1992) showed a negative correlation between soil temperatures following sowing, and the severity of attack. The attack was most severe when the temperature was in the range 6-7^{o}C. Polisenka *et al*. (1998) also reported a negative correlation between soil temperature and percentage infection; the lower the temperature, the higher the rate of infection. This may well be due to an interaction between the rate of growth of the germinating seed and the growth of the bunt spores on the seed. There is effectively a ‘race’ between the germinating seedling and the bunt spores attempting to infect the seedling. This is not a simple race between a germinating spore and a germinating seed. The bunt spores on the seed surface normally germinate with the seed. Each produces a short fungal thread terminating in a cluster of elongated cells. These, after a process of conjugation, produce secondary spores. These infect the coleoptiles of the young seedlings before the emergence of the first true leaves. This ‘delay’ in producing infective spores can, under conditions favourable to the seedling, allow the wheat plant to escape infection. The reverse is true for seeds germinating in cool soils when the seed germinates slowly, allowing time for the bunt spores to germinate and infect. Thus, late-sown winter wheat is particularly at risk of infection from bunt. Consequently, countries with a high proportion of late-sown wheat, or wheat being sown into cold soils, may well opt for lower thresholds for treatment. In the UK, early sowing of wheat into warm autumn soils may lead farmers to use home-saved untreated seed as the perceived risk of bunt infection is small. Warm, moist seedbeds result in rapid germination of seeds and good establishment. Even seed carrying high levels of bunt can germinate quickly and establish well under good conditions. Bunt infection of seed has no effect on germination (unlike *Microdochium* or *Fusarium* infection where the infection can be deep within the seed). Consequently, where seedbeds are warm and moist, farmers may well decide to use untreated farm-saved seed. This is particularly the case where the parent crop was grown from certified, treated seed, as high levels of bunt are very unlikely to occur. Late sown crops sown into cold soils pose a higher risk and seed would normally be tested and thresholds applied stringently.

2.4.2. Seedling blight (*Microdochium nivale*)

In the UK, seedling blight caused by *Microdochium nivale* is the most important seed-borne disease of wheat. Its importance is often overlooked by farmers as fungicide seed treatment of wheat seed to protect against seedling blight is the norm, and so poor establishment due to this disease is rarely seen. The usual threshold for treatment (or more usually, a threshold for <u>not</u> treating) is 10% seed infection. This threshold was confirmed in the HGCA project 'Cereal seed health and seed treatment strategies' (Cockerell *et al*, 2004). Farmers and advisers frequently use this threshold as a negative threshold i.e. seed lots with levels below this threshold may be sown without a fungicidal seed treatment (taking account of other seed-borne diseases present). Soil temperature and seedbed conditions can have a marked effect on the risk of seedling blight. Warm, moist seedbeds result in rapid germination of seeds and good establishment. Even seed lots carrying high levels of infection with *Microdochium* can germinate quickly and establish well under good conditions. These are often the conditions under which farmers may well decide to use farm-saved seed. They have the seed readily available and can adjust the seed rate to compensate for lower germination (if necessary) at minimal cost. It is very often a decision made for practical reasons, not for cost-saving. Later sown crops going into colder, wetter seedbeds would be at greater risk and seed treatment to protect against *Microdochium* seedling blight would be the norm, even if seed-borne disease levels were close to the 10% threshold. *Microdochium* seedling blight is much less serious in barley and consequently a higher threshold for treatment (30%) is normally applied.

2.4.3. Leaf stripe (***Pyrenophora graminea***)

Leaf stripe can kill seedlings as they emerge. This is unusual but can occur if soil conditions are very poor (especially cold and wet). Early sowing into warm seed beds ensures that this stage of the disease is rarely seen. The fungus is present on the seed surface and as mycelium in the seed coat. As the coleoptile emerges, the fungus invades the tissue and penetrates through to the emerging first leaf. The fungus grows through successive leaf sheaths, producing the characteristic symptoms on each leaf until it infects the ear which often remains in the leaf sheath.

This is potentially the most serious seed-borne disease of barley. If seed from affected crops is re-sown without an effective fungicidal seed treatment being applied, the disease can multiply very significantly and produce large yield losses. If seed is saved and re-sown repeatedly, complete crop loss is possible within a few generations of seed multiplication. Most barley seed is currently treated with a fungicidal seed treatment to control leaf stripe and so symptoms in commercial crops are usually rare. There is little scope for adjusting the advisory threshold of 2%, even under ideal sowing conditions.

2.4.4. Covered smut (***Ustilago hordei***)

The disease is very rare in the UK and usually only found in crops grown repeatedly from untreated seed. Because the spores are present only on the surface of the seed, covered smut is readily controlled by the use of surface acting fungicidal seed treatments. It is not a major consideration when deciding upon seed treatment.

2.5. Comparison of EU thresholds for seed-borne diseases

Few EU countries publish in detail both advisory and statutory thresholds for seed-borne diseases. Denmark is unusual in that it publishes in detail the thresholds applied for all cereal seed-borne diseases. These are given below. For other countries a summary of the thresholds applied is given in the following tables.

Table 5. Recommended threshold levels for seed-borne diseases in Denmark

Crop	Disease	Certified seed C1	Certified seed C2
Winter wheat	Common bunt	Recorded occurrence	10 spores/g
	Seedling blight (*Fusarium* spp.)[1) 2)]	15%	15%
	Glume blotch (*Septoria nodorum*)[2)]	15%	15%
Spring wheat	Common bunt (*Tilletia tritici*)	Recorded occurrence	10 spores/g
	Seedling blight (*Fusarium* spp.)[1) 3)]	30%	30%
	Glume Blotch (*Septoria nodorum*)[3)]	15%	15%
Winter triticale	Common bunt (*Tilletia tritici*)	Recorded occurrence	10 spores/g
	Stripe smut (*Urocystis occulta*)	Recorded occurrence	10 spores/g
	Seedling blight (*Fusarium* spp.)[1) 2)]	15% [3)]	15% [3)]
	Glume blotch (*Septoria nodorum*)[2)]	15%	15%
Spring triticale	Common bunt (*Tilletia tritici*)	Recorded occurrence	10 spores/g
	Stripe smut	Recorded occurrence	10 spores/g
	Seedling blight (*Fusarium* spp.)[1) 3)]	30%	30%
	Glume blotch (*Septoria nodorum*)[3)]	15%	15%
Rye	Stripe smut (*Urocystis occulta*)	Recorded occurrence	10 spores/g
	Seedling blight (*Fusarium* spp.)[1)]	15%	15%
Oats	Leaf spot		
	Seedling blight (*Fusarium* spp.)[1)]	30%	30%
	Smut (*Ustilago avenae*)		

Crop	Disease	Certified seed C1	Certified seed C2
Winter barley	Leaf stripe (*Pyrenophora graminea*)	Recorded occurrence	5%
	Net blotch (*Pyrenophora teres*)	5% for susceptible varieties (PVO 3) [4)] 15% for susceptible or moderately resistant varieties (PVO1-2) 25% for resistant varieties (PVO 0)	5% for susceptible varieties (PVO 3) [4)] 15% for susceptible varieties or moderately resistant varieties (PVO1-2) 25% for resistant varieties (PVO 0)
	Seedling blight (*Fusarium* spp.)[1)]	15%	15%
	Loose smut (*Ustilago nuda*)	Recorded occurrence	2%
Spring barley	Leaf stripe (*Pyrenophora graminea*)	Recorded occurrence	5%
	Net blotch (*Pyrenophora teres*)	5% for susceptible varieties (PVO 3) [4)] 15% for susceptible or moderately resistant varieties (PVO1-2) 25% for resistant varieties (PVO 0)	5% for susceptible varieties (PVO 3) [4)] 15% for susceptible varieties or moderately resistant varieties (PVO1-2) 25% for resistant varieties (PVO 0)
	Seedling blight (*Fusarium* spp.)[1)]	30%	30%
	Loose smut (*Ustilago nuda)*	Recorded occurrence	2%

[1] Several Fusarium species, e.g. F. culmorum, F. avenaceum as well as Microdochium nivale and Bipolaris

[2] In winter wheat and winter triticale the sum of seedling blight + Septoria nodorum must not exceed 15%

[3] In spring wheat and spring triticale the sum of seedling blight + Septoria nodorum must not exceed 30%; however, max 15% S. nodorum

[4] PVO: Characterisation of resistance to net blotch in Crop Protection Online

2.5.1. Winter wheat

*Bunt (*Tilletia tritici*)*

Table 6. National seed-borne disease thresholds for *Tilletia tritici*

Country	Standard/Seed Treatment Threshold	Statutory/ Advisory
Austria	10 spores/seed	Statutory
Czech Rep.	10 spores/300 seed*	Statutory
Denmark	10 spores/g seed	Statutory
France	0 spores	
Germany	10-50 spores per seed**	Advisory
Sweden	0 spores	Statutory
UK	1 spore/seed	Advisory

* Evaluated as *Tilletia* spp.

** Organic seed only

*Seedling blight (*Microdochium nivale*)*

Table 7. National seed-borne disease thresholds for *Microdochium nivale*

Country	Standard/Seed Treatment Threshold	Statutory/ Advisory
Austria	10%*/15%**	Statutory
Czech Rep.	-	-
Denmark	15%	Statutory
France	-	-
Germany	-	-
Sweden	30%***	Statutory
UK	10%	Advisory

*Basic & C1

** C2

*** Sum of *M.nivale, Fusarium spp.,C. sativus & P. nodorum*.

2.5.2. Winter barley

*Loose smut (*Ustilago nuda*)*

Table 8. National seed-borne disease thresholds for *Ustilago nuda*

Country	Standard/Seed Treatment Threshold Seed Category			Statutory/ Advisory
	Basic	**C1**	**C2**	
Austria	0.1%	0.1%	0.5%	Statutory
Czech Rep.	0.8%	2.0%	2.0%	Statutory
Denmark	0	0	2.0%	Statutory
France	-	-	-	
Germany*		0.3%	0.3%	Advisory
Ireland	0.2%	0.2%	0.2%	Advisory
Sweden**	0.2%	0.3%	0.3%	Statutory
UK	0.5%	0.5%	0.5%	Statutory
UK (HVS)	0.1%	0.2%	0.2%	Statutory

*Organic seed only

**Prebasic (0.1%)

*Leaf stripe (*Pyrenophora graminea*)*

Table 9. National seed-borne disease thresholds for *Pyrenophora graminea*

Country	Standard/Seed Treatment Threshold Seed Category			Statutory/ Advisory
	Basic	**C1**	**C2**	
Austria	2.0%	2.0%	2.0%	Statutory
Czech Rep.	2.0%	2.0%	2.0%	Statutory
Denmark	0	0	5%	Statutory
France	-	-	-	
Germany	-	-	-	
Ireland	-	-	-	
Sweden*	15.0%	15.0%	15.0%	Statutory
UK	2.0%	2.0%	2.0%	Advisory

*Sum of *P. graminea* & *P. teres*

2.5.3. Organisations carrying out seed testing and certification information.

Table 10. Organisations performing seed health testing for certification and/or advisory purposes.

Country	Organisation				
	OSTS (Government)	Seed Company	Independent Lab.	University	Research Institute
Austria					
Czech Republic					
Estonia					
France					
Germany					
Ireland					
Norway					
Sweden					
UK					

Table 11. Proportion of national crops grown from certified seed

Country	Wheat		Barley		Oats		Rye	Triticale
	Winter	Spring	Winter	Spring	Winter	Spring		
Austria	46	90	66	42		52	55	85
Czech Republic	72	87	74	83		58	41	63
France	55	55						
Germany	51	65	59	57		49	63	73
Ireland	80	90	90	95	95	95		
Norway								
Slovakia								
Sweden								
UK	55		60	65				

Table 12. Proportion of national crops grown from farm-saved seed

Country	Wheat		Barley		Oats		Rye	Triticale
	Winter	Spring	Winter	Spring	Winter	Spring		
Austria	54	10	34	58		48	45	15
Czech Republic	28	13	26	17		42	59	37
France	45	45						
Germany	49	35	41	43		51	37	27
Ireland	20	10	10	5	5	5		
Norway								
Slovakia								
Sweden								
UK	45		40	35	30			

Table 13. Proportion of certified seed sown untreated

Country	Wheat		Barley		Oats		Rye	Triticale
	Winter	Spring	Winter	Spring	Winter	Spring		
Austria	13	41	11	33		72	35	26
Czech Republic*	10-20	10-20	10-20	10-20	10-20	10-20	10-20	10-20
France	No response							
Germany	5	5	5	20	5	20	5	5
Ireland	0	0	0	0	0	0		
Norway								
Slovakia								
Sweden								
UK	<1	<1	<1	<1				

* dependant on proportion of organic seed

Table 14. Proportion of farm-saved seed sown untreated

Country	Wheat		Barley		Oats		Rye	Triticale
	Winter	Spring	Winter	Spring	Winter	Spring		
Austria	25	40	30	40		80	50	50
Czech Republic*	<10	<10	<10	<10		100	<10	<10
France	No response							
Germany	?	?	?	?	?	?	?	?
Ireland	0	0	0	0	0	0		
Norway								
Slovakia								
Sweden								
UK	8		3	14	25		5	85

*Estimate

2.6. Organic seed production

The processes of organic seed production mean that the seed will have to have undergone at least two generations of multiplication without use of conventional treatments. The absence of treatments means that diseases such as smuts and bunt could multiply freely, and that in some seasons seed might be affected by high levels of *Microdochium nivale* and *Phaeosphaeria nodorum*. If planted, the presence of high levels of these seedling blights could lead to significant loss of plant stand.

The European Council Regulation (EEC) No. 2092/91 states that organic seeds must be used where available. However, it also allows non-organic seed to be used where no suitable/appropriate organic alternative is available.

The European Commission Regulation (EC) No. 1452/2003, published in August 2003, does not, as of 1 January 2004, allow treated seeds to be used. There are also no grounds for a derogation to use non-organic seed on the grounds of seed quality if the variety a user wants to use is registered in the database.

A survey of organic cereal users and organic cereal growers was carried out by SAC as part of a review of organic cereal production funded by the HGCA in 2000 (Taylor et al, 2001). The survey found the most commonly grown organic cereals to be winter wheat (47% of surveyed farms), spring barley (39%) and spring oats (34%). Winter oats and spring wheat were popular in the South West of the UK. Triticale, grown by 19% of farmers, was considered to be a useful feed grain for organic rotations. Expected grain yields ranged from 3.7 tonnes/ha for spring barley to 4.7 tonnes/ha for winter wheat. Less than a quarter of surveyed crops were sown with home-saved seed; seed source (home-saved, bought-in organic, bought-in non-organic) did not significantly affect grain yield. 69% of growers used higher seed rates than used for conventional cereal crops; high seed rates did not result in increased yields but protected against field losses.

In a Defra-funded project (OF033), NIAB obtained information on which seed-borne diseases, including ergot, may cause problems in the organic seed production chain of wheat, barley, oats and triticale, and to examine any relationship between organic husbandry conditions (seed rate, sowing date, rotation etc.) and incidence/severity of disease. A total of 676 samples were tested between 2002 and 2005. Results showed that most samples had higher health status than the conventional treatment thresholds. However, there were occasional problems, most notably in the case of bunt on wheat, where very high levels of infection were seen. This seed would have been unsuitable for further multiplication as seed, or for ware production. Ergot (*Claviceps purpurea*) was present at high levels (e.g. over 50 pieces per kg of seed) in several samples. *Microdochium nivale* sometimes reached high levels on wheat seed in seasons favourable to the disease, but similar levels were also seen in conventional samples received for testing at NIAB. Bunt was occasionally found at high levels, and if used, the infection would have caused extensive crop loss.

Despite the overall high health status of the samples tested, it was clear that problems could occur. Bunt represents one of the most serious disease threats to organic wheat as whole crops may be lost. Occasionally, commercial C1 generation seed lots with comparatively low levels of infection, just above the treatment threshold, were found, and in these cases, merchants withdrew them from further organic production. Testing and removal of infected lots has undoubtedly contributed to disease free seed later in the production chain. However, it can result in the loss of valuable seed, possibly delay the introduction of new varieties, and in extreme situations, could limit the overall supply of organic seed.

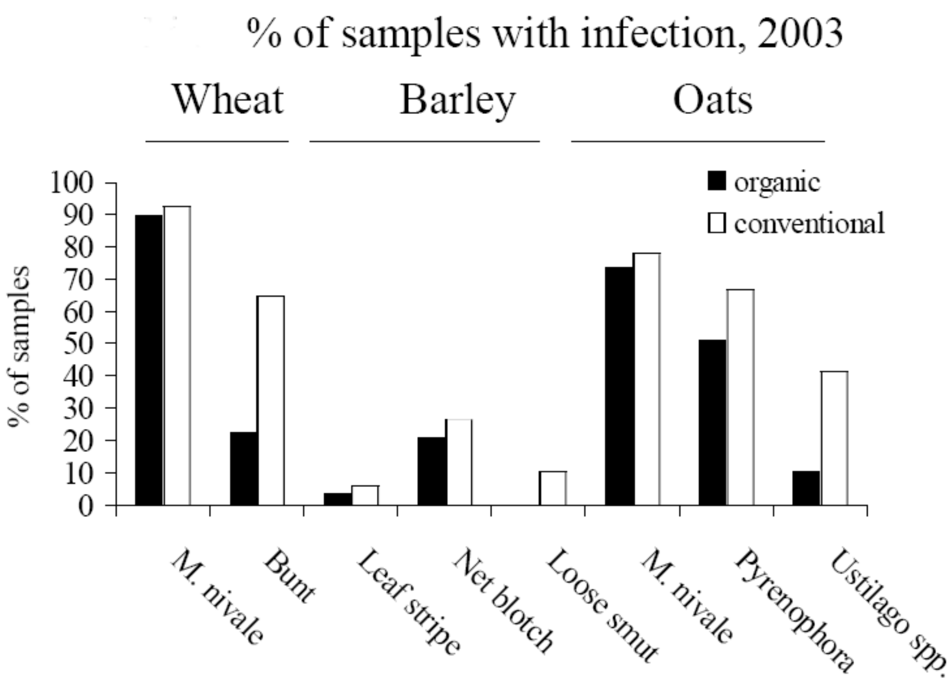

Figure 1. Defra-funded project (OF033), NIAB information on seed-borne diseases present in the organic seed production chain

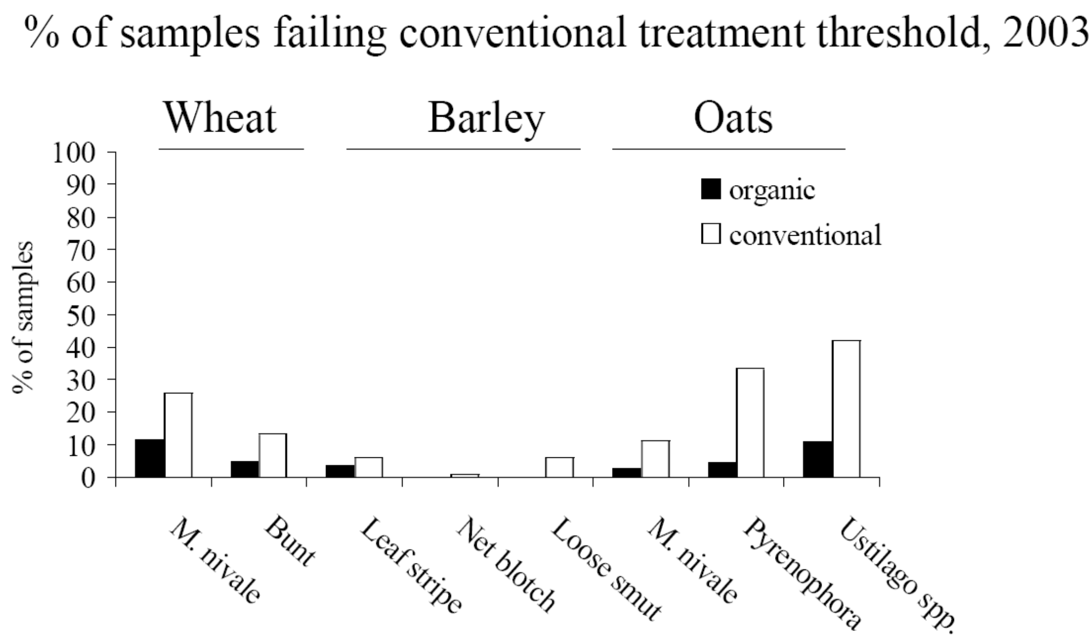

Figure 2. Defra-funded project (OF033), NIAB information on seed-borne diseases present in the organic seed production chain

2.7. Organic seed-treatments

Through agriculture's history, seed borne diseases have been one of the most serious problems in cultivation. From ancient Greece and Rome and until the start of the 20th century, control of bunt in wheat, in particular, has played an important role in the history of seed health and seed treatment. The development of organo-mercury seed dressings in 1913 radically changed this situation within a few years. The mercury seed dressings were effective against most of the seed-borne diseases, and they were cheap and easy to use. Some organic certifying bodies allow application of copper-salts and bio-agents, but the use of these does to some extent conflict with the fundamental principles of organic disease management.

As part of the Defra-funded project (OF033), NIAB carried out seed treatment trials in 2004 and 2005. Products and processes selected for evaluation comprised examples of biological, micronutrient and physical treatments. Several of the products (e.g. Garlic extract, EM1) are currently available for agricultural and horticultural use, and would be appropriate for organic systems according to consultations with the Soil Association during the course of the project. However, none of the products tested were sold specifically as seed treatments. Trials with infected seed wheat and barley in the first year and wheat only in the second year, were carried out at NIAB, Cambridge.

None of the treatments tested suppressed loose smut or leaf stripe on barley. None of the treatments used in 2004 significantly improved establishment (plant counts) when wheat seed had a high level (30%) of *Microdochium nivale* seedling blight, and none significantly increased final yield. In 2005, one of the biological treatments tested, significantly improved plant establishment, although effects on yield were non-significant. Both biological products (Cerall and the Crompton product) suppressed bunt in 2005, as did Radiate (ammonium and zinc ammonium complex), though the latter had no significant effect in 2004. The hot air treatment also reduced bunt in 2005, though the effect was less marked in 2004. The range in the level of disease control was very large. In the worst cases no control was achieved. The highest level of disease control was 74%. This level of control is not commercially acceptable and would result in very rapid build up of the disease in crops and crop failure in many cases. Results for bunt are summarised in the table 15.

Table 15. Counts of Bunted ears per plot (12m) in NIAB seed treatment trials, 2004 and 2005.

Treatment 2004	Bunted ears/plot 2004
Untreated	36.7
Sibutol	0
Radiate	32.7
NMS	35.3
EM1	42.0
EM1 + micronutrient	48.7
Tricet Micronutrient	43.3
Bacillus subtilis	38.7
Garlic	35.3
Hot air (90 secs)	27.3
Lsd (p=0.05)	8.48

Treatment 2005	Bunted ears/plot 2005
Untreated	28.5
Sibutol Secur	0
Radiate	7.3
Cerall	7.5
Crompton	8.5
30 secs hot air	9.8
60 secs hot air	18.8
90 secs hot air	14.8
	10.13

Various seed dressings, which are permitted in organic farming, have been developed. In Germany Tillecur, which is based on mustard flour, is used. This agent is effective against bunt (*Tilletia tritici*) (Borgen and Kristensen 2001, Spiess 2000). Experiments with acetic acid (vinegar) as a seed treatment have been carried out and shown to be effective against bunt and leaf stripe (Borgen and Nielsen 2001). Due to the present interpretation of the EU regulations this agent, along with vinegar, is not permitted.

Biological treatments with bacteria or fungi are a potential means of control. At present few products are approved in the EU. Products such as Cedomon (*Pseudomonas chlororaphis*) can be used in some EU countries. Milk powder can control bunt but high levels of control can only be reached at high doses, where the germination and vigour of the seeds are reduced (Borgen and Kristensen, 2001). In some EU countries copper-salts are used as seed dressing in organic farming. Copper has been used as a seed treatment in Europe for 200 years but it is not as effective as modern seed treatments and it's use for plant protection in organic farming is controversial. Most wine producing countries allow the use, while the Scandinavian and some other countries have opposed the use of copper in organic farming.

The Danish Research Centre for Organic Food and Farming, in association with the Danish Institute for Agricultural Sciences, carried out an extensive range of experiments between 2001-2005, testing many alternative methods for seed treatment suitable for organic systems (Nielsen 2006). A summary of their results are described below.

2.7.1. Brush cleaning

Spores of *Tilletia tritici* are present in seed lots mainly as free spores on the seed. Therefore, a seed lot could theoretically be cleaned of spores if the spores are removed mechanically from the seed lot. The project tested the effect of a brush cleaner to remove spores from seed lots. The brush cleaner removed up to 97% of the present free spores, given that bunt balls were removed before treatment.

2.7.2. Seed size separation

Seed-infecting diseases, particularly *Fusarium* spp., can affect seed size, and seed size separation may therefore remove more infected seeds than healthy. A number of experiments were carried out investigating this hypothesis. It was concluded that removal of small size and lightweight seed in some seed lots could reduce the infection level of *Fusarium*, *Phaeosphaeria nodorum*, *Pyrenophora graminea* and *Ustilago nuda*, whereas in other seed lots there was no effect of seed separation. Clearly a number of other factors influence seed size such as fertilisation, water availability and weed suppression. In many cases these factors overrule the effect of the seed-borne diseases. The effects were not consistent enough to be used in practice.

2.7.3. Heat treatment

A SonoSteam technique (combined ultrasound and steam treatment) was tested on a range of seed-borne diseases. The technique was tested in a pilot study on Pyrenophora teres, P. graminea, Fusarium, Phaeosphaeria nodorum and Tilletia tritici. It was concluded that the technique had promising effects on the diseases but was not developed to a stage where it could be used commercially. Another technique treating the seed with hot humid air (60-80^{o}C, 90 RH 60-320 sec.) was also tested on bunted seed with some success.

2.7.4. Hot water treatment

Seeds were treated using the traditional hot water treatment and good control of bunt was possible but it is considered impractical in modern commercial seed plants.

2.7.5. Drum dryer

Experiments with a drum dryer heat treatment show that the method had a significant effect on some seed-borne diseases, but without effect on other diseases. The results on control of net blotch in barley were promising, but effects on bunt were less good, giving up to 80% control of the disease, well short of what is required commercially.

Many of these alternative methods can give significant levels of control in experiments. Some of the methods are impractical, others commercially non-viable but in general the level of control achievable is less than that required in commercial practice. Bunt in particular requires very high levels of control (99-100%) otherwise the disease can still be economically damaging. Consequently, at present there are no clear alternatives to the use of commercial seed treatments in seed production. Seed testing can allow seed lots carrying important diseases to be rejected but currently non-chemical 'organic' seed treatments are not sufficiently effective. In many countries the emphasis has now moved to looking for varietal resistance to seed-borne diseases.

2.8. Discussion

It is clear from the data presented here that there is considerable variation amongst the countries surveyed of the perceived threats posed by individual seed-borne diseases. Perhaps as a consequence, there is also a wide range of thresholds that are applied in order to control the diseases. Some of this variation may be explicable in that there will be considerable variation in the amount of spring and winter cropping in these countries and this will affect the occurrence and severity of some seed-borne diseases. Some of the variation in thresholds and perceived threat from seed-borne diseases is related to climatic conditions. In most countries there is little interpretation of thresholds, i.e. they are applied strictly. In the UK there is more of a tendency for advisers to use the advisory thresholds but adapt them depending on individual farm circumstances. Why this is the case is not obvious, but is perhaps linked to the predominance of independent crop advisers in the UK, whereas in most EU countries there are state or government advisers who may apply thresholds more strictly. The use of farm-saved seed is common in many countries with typically 40-50% of crops grown from non-certified seed. The amount of this that is sown without seed treatment varies considerably between countries and crops. Austria seems to have a very high proportion of both certified and farm-saved untreated seed, some of which may be organic crops. Most countries have very little untreated seed, typically less than 10% of winter wheat and winter barley.

Seed testing is clearly a very important tool in the management of seed quality for sowing and can be used by the seed trade to evaluate the quality of their seed prior to processing or by growers who save their own seed. The amount of seed testing carried out is very variable but capacity for seed testing is usually the limiting factor. In practice only a small percentage of seed lots are tested for non-statutory seed-borne pathogens such as bunt or seedling blight. Certified seed is officially tested to ensure that certain minimum standards are met for germination, purity, other seed content, and some seed-borne diseases. Fungicidal seed treatment is the norm with the vast majority of seed treated as a routine.

In Denmark, most organic farmers use organically propagated cereals for seed and all seed lots are tested for infections of seed-borne pathogens before sowing. About 50% of all seed lots are discarded based on this assessment, but huge differences occur between year and crop, which makes planning of seed production virtually impossible. In some years up to 90% of the seed lots may be discarded.

Clearly each EU country has arrived at its threshold levels in different ways, largely through experimentation, some of which was carried out many years ago. There is now considerable variation between countries in both the perceived importance of individual diseases and the thresholds applied. It is arguable that each country's threshold is perfectly valid as it has been derived from 'local' experimentation. However, in each of the thresholds there is a built-in degree of caution and this varies depending on how risk-averse the researcher or certifying authority is. Most thresholds are applied in a highly risk-averse way. This is appreciated in the UK, where advisory thresholds are interpreted and applied by independent advisers who use local knowledge of climate, soil conditions and seed treatment effectiveness. This is much less common in other EU countries.

There is no immediate need to attempt to understand the variation in thresholds applied, nor to try and standardise thresholds in the EU. However, it would certainly be of value to pursue the reasoning behind existing thresholds and to share more widely the research that has been done to arrive at these thresholds. In this way it may be possible for researchers in the EU to share experiences and to improve or refine thresholds for the future. The ENDURE project offers the perfect platform to pursue this and hopefully in the future, funding may become available to allow this to happen.

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APPENDIX 1: PERCEIVED IMPORTANCE OF SEED-BORNE DISEASES OF WHEAT, RYE AND TRITICALE

Cochliobolus sativus

Country	Wheat		Rye	Triticale
	Winter	**Spring**		
Austria	Zero	Zero	Zero	Zero
Czech Republic	Medium	Zero	Zero	Zero
France	Medium	Medium		Medium
Germany	Low	Medium	Low	Low
Ireland	Low	Low	Zero	
Norway				
Slovakia	Low	Low	Low	Low
Sweden	Low	Low	Low	Low
UK	Low	Low		

Fusarium graminearum

Country	Wheat		Rye	Triticale
	Winter	**Spring**		
Austria	High	High	Medium	High
Czech Republic	Medium	Medium	Medium	Medium
France	High	High		High
Germany	High	High	Low	Medium
Ireland	High	High	Zero	
Norway				
Slovakia	Low	Low	Low	Low
Sweden	High	High	Medium	Medium
UK	Medium	Low	Low	Low

***Fusarium* spp. (excl. *F. graminearum*)**

Country	Wheat		Rye	Triticale
	Winter	**Spring**		
Austria	High	High	Medium	High
Czech Republic	High	High	High	High
France	High	High		High
Germany	High	High	Medium	Medium
Ireland	High	High	Zero	High
Norway				
Slovakia	High	Medium	High	High
Sweden	High	High	Medium	Medium
UK	Low	Low	Low	Low

Microdochium nivale				
Country	**Wheat**		**Rye**	**Triticale**
	Winter	**Spring**		
Austria	High	Medium	High	High
Czech Republic	Medium	Zero	High	Medium
France	High	High		High
Germany	High	Medium	Medium	Medium
Ireland	High	High	Zero	High
Norway				
Slovakia	Medium	Zero	High	Low
Sweden	High	Medium	High	High
UK	High	High	High	High

Phaeosphaeria nodurum **(Septoria nodurum)**				
Country	**Wheat**		**Rye**	**Triticale**
	Winter	**Spring**		
Austria	High	High	Zero	Medium
Czech Republic	High	High	Low	Low
France	High	High		High
Germany	High	High	Medium	Medium
Ireland	Medium	Medium	Zero	High
Norway				
Slovakia	High	Medium	Medium	High
Sweden	High	High	Low	Medium
UK	High	High	Medium	High

Tilletia **spp.**				
Country	**Wheat**		**Rye**	**Triticale**
	Winter	**Spring**		
Austria	High	High	Zero	Low
Czech Republic	High	Low	Low	Low
France	High	High		High
Germany	High	High	Low	Low
Ireland	Low	Low	Zero	
Norway				
Slovakia	High	Medium	Medium	High
Sweden	High	Low	Zero	Low
UK	High	High		

Tilletia controversa				
Country	**Wheat**		**Rye**	**Triticale**
	Winter	**Spring**		
Austria	High	Zero	High	High
Czech Republic	High	Low	Low	Low
France	High	High		High
Germany	Medium	Medium	Low	Low
Ireland	Low	Low	Zero	
Norway				
Slovakia	High	Medium	Medium	High
Sweden	High	Low	Zero	Low
UK	Zero	Zero	Zero	Zero

Ustilago tritici				
Country	**Wheat**		**Rye**	**Triticale**
	Winter	**Spring**		
Austria	Medium	Medium	Zero	Zero
Czech Republic	High	High	Medium	Medium
France	Medium	Medium		Medium
Germany	Low	Low	Zero	Low
Ireland	Low	Low	Zero	
Norway				
Slovakia	Medium	Low	Medium	Medium
Sweden	Zero	Low	Zero	Zero
UK	Low	Low	Zero	Low

Urocystis occulta				
Country	**Wheat**		**Rye**	**Triticale**
	Winter	**Spring**		
Austria			Low	Zero
Czech Republic	Zero	Zero	Medium	Medium
France				
Germany				
Ireland				
Norway				
Slovakia				
Sweden				
UK	Zero	Zero		

APPENDIX 2: PERCEIVED IMPORTANCE OF SEED-BORNE DISEASES OF BARLEY

Cochliobolus sativus		
Country	**Barley**	
	Winter	**Spring**
Austria	Low	Medium
Czech Republic	Medium	Zero
France	High	High
Germany	Low	Medium
Ireland	Low	Low
Norway		
Slovakia	Low	Low
Sweden	Low	High
UK	Low	Medium

Fusarium graminearum		
Country	**Barley**	
	Winter	**Spring**
Austria	Medium	Low
Czech Republic	Medium	Medium
France	High	High
Germany	Low	Low
Ireland	High	High
Norway		
Slovakia	Low	Low
Sweden	High	High
UK	Low	Low

***Fusarium* spp. (excl. *F. graminearum*)**		
Country	**Barley**	
	Winter	**Spring**
Austria	Medium	Low
Czech Republic	High	High
France	High	High
Germany	Medium	Medium
Ireland	High	High
Norway		
Slovakia	Low	Low
Sweden	High	High
UK	Low	Low

Microdochium nivale		
Country	**Barley**	
	Winter	**Spring**
Austria	High	Medium
Czech Republic	Medium	Zero
France	High	High
Germany	Medium	Low
Ireland	High	High
Norway		
Slovakia	Low	Zero
Sweden	High	Medium
UK	Medium	Medium

Pyrenophora graminea		
Country	**Barley**	
	Winter	**Spring**
Austria	Low	High
Czech Republic	High	High
France	High	High
Germany	Medium	Medium
Ireland	High	High
Norway		
Slovakia	Medium	High
Sweden	High	High
UK	High	High

Pyrenophora teres		
Country	**Barley**	
	Winter	**Spring**
Austria	Medium	Medium
Czech Republic	Medium	Medium
France	High	High
Germany	High	High
Ireland	High	High
Norway		
Slovakia	Medium	High
Sweden	High	High
UK	Medium	Medium

Ramularia collo-cygni		
Country	**Barley**	
	Winter	**Spring**
Austria	Medium	Medium
Czech Republic	Low	Low
France		
Germany	High	High
Ireland	Medium	Medium
Norway		
Slovakia	Low	Low
Sweden	Zero	Zero
UK	Medium	Medium

Rhynchosporium secalis		
Country	**Barley**	
	Winter	**Spring**
Austria		
Czech Republic	Low	Low
France		
Germany	High	Medium
Ireland	Medium	Medium
Norway		
Slovakia	Medium	High
Sweden	Zero	Zero
UK	Medium	Medium

Ustilago hordei		
Country	**Barley**	
	Winter	**Spring**
Austria	Low	Low
Czech Republic	High	High
France		
Germany	Medium	Medium
Ireland	Low	Low
Norway		
Slovakia	Medium	Low
Sweden	Zero	Zero
UK	Low	Low

Ustilago nuda		
Country	**Barley**	
	Winter	**Spring**
Austria	High	High
Czech Republic	High	High
France	High	High
Germany	High	High
Ireland	High	High
Norway		
Slovakia	Medium	High
Sweden	High	High
UK	High	High

APPENDIX 2: PERCEIVED IMPORTANCE OF SEED-BORNE DISEASES OF OATS

Cochliobolus sativus		
Country	**Oats**	
	Winter	**Spring**
Austria		Zero
Czech Republic	Medium	Medium
France	High	High
Germany	Low	Low
Ireland	Low	Low
Norway		
Slovakia	Zero	Zero
Sweden		Low
UK	Low	Low

Fusarium graminearum		
Country	**Oats**	
	Winter	**Spring**
Austria		Low
Czech Republic	Zero	Zero
France	High	High
Germany	Medium	Medium
Ireland	High	High
Norway		
Slovakia	Zero	Zero
Sweden		High
UK	Low	Low

***Fusarium* spp. (excl. *F. graminearum*)**		
Country	**Oats**	
	Winter	**Spring**
Austria		Low
Czech Republic	High	High
France	High	High
Germany	Medium	Medium
Ireland	High	High
Norway		
Slovakia	Zero	Low
Sweden		High
UK	Low	Low

Microdochium nivale		
Country	**Oats**	
	Winter	**Spring**
Austria		Zero
Czech Republic	Zero	Zero
France	High	High
Germany	Medium	Medium
Ireland	High	High
Norway		
Slovakia	Zero	Zero
Sweden		Medium
UK	High	High

Pyrenophora avenae		
Country	**Oats**	
	Winter	**Spring**
Austria		Low
Czech Republic	Medium	Medium
France	High	High
Germany	High	High
Ireland	Medium	Medium
Norway		
Slovakia	Zero	Low
Sweden		High
UK	Medium	Medium

Ustilago avenae		
Country	**Oats**	
	Winter	**Spring**
Austria		Low
Czech Republic	Low	Low
France	High	High
Germany	High	High
Ireland	Low	Low
Norway		
Slovakia	Zero	Medium
Sweden		High
UK	Medium	Medium