EFSA Journal 2010; 8(6):1621

SCIENTIFIC OPINION

Scientific opinion on a quantitative pathway analysis of the likelihood of *Tilletia indica* M. introduction into EU with importation of US wheat[1]

EFSA Panel on Plant Health (PLH)[2, 3]

European Food Safety Authority (EFSA), Parma, Italy

ABSTRACT

The European Commission requested EFSA to provide a scientific opinion on the USDA APHIS quantitative pathway analysis on likelihood of Karnal bunt introduction with importation of US wheat for grain into EU and desert durum wheat for grain into Italy. EFSA was also requested to indicate whether the US bunted kernel standard would provide equivalent protection against introduction of *Tilletia indica* into EU, compared to the existing EU import requirement. The Panel on Plant Health reviewed pathway scenarios, model and parameters and found several shortcomings regarding model equations and parameter values, particularly a lack of scientific evidence for the infection threshold. Simulations were computed, for importations of US wheat into EU and desert durum wheat into Italy, based on original model and an updated model with revised parameter values. Model output was teliospores number per hectare on soil surface of each EU country. Simulated teliospores numbers entering EU were lower with the updated than with the original model. These results showed a high uncertainty, underestimated with the original model, over the number of teliospores entering each EU country. Sensitivity analysis showed several key parameters (proportion of bunted kernels in Arizona regulated counties, number of Arizona positive hectares and number of teliospores per bunted kernel) strongly influencing number of teliospores entering the EU. In addition, high sensitivity indices were obtained with the updated wheat model for several parameters related to EU country characteristics. Further research is needed to refine parameter values, to reduce uncertainty and to determine relationship between teliospores number on soil surface and number of bunted kernels resulting from infection of a wheat plant. The Panel concluded that the US bunted kernel standard does not provide a level of protection equivalent to EU requirements and that such level of protection could only be warranted by measures which include testing at harvest and before shipment to detect *T. indica* teliospores.

KEY WORDS

Wheat, durum wheat, desert durum, grain, import, mill, pathway, Karnal bunt, *Tilletia indica*, teliospores, model, stochastic, probabilistic.

---

[1] On request from the European Commission, Question No EFSA-Q-2009-00760, adopted on 11 May 2010.

[2] Panel members: Richard Baker, Thierry Candresse, Erzsébet Dormannsné Simon, Gianni Gilioli, Jean-Claude Grégoire, Michael John Jeger, Olia Evtimova Karadjova, Gábor Lövei, David Makowski, Charles Manceau, Maria Navajas, Angelo Porta Puglia, Trond Rafoss, Vittorio Rossi, Jan Schans, Gritta Schrader, Gregor Urek, Johan Coert van Lenteren, Irene Vloutoglou, Stephan Winter and Marina Zlotina. One member of the Panel did not participate in the discussion on the subject referred to above because of potential conflicts of interest identified in accordance with the EFSA policy on declarations of interests. Correspondence: plh@efsa.europa.eu

[3] Acknowledgement: The Panel wishes to thank: the members of the Working Group on *Tilletia indica* for the preparatory work for this opinion: Michael John Jeger, Gábor Lövei, David Makowski, Angelo Porta Puglia, Trond Rafoss and Irene Vloutoglou; the hearing expert Guillermo Fuentes Dávila for the presentations on biological and epidemiological aspects of Karnal bunt; the hearing experts Filippo Bertuzzi, Luigi Pianu and Roberto Ranieri for the presentation on the wheat pathway and the Italian durum wheat milling industry; and EFSA's staff members Olaf Mosbach-Schulz, Giuseppe Stancanelli and Tilemachos Goumperis for the support provided to this EFSA scientific output.

Suggested citation: EFSA Panel on Plant Health (PLH); Scientific opinion on a quantitative pathway analysis of the likelihood of *Tilletia indica* M. introduction into EU with importation of US wheat. EFSA Journal 2010; 8(6):1621. [88 pp.]. doi:10.2903/j.efsa.2010.1621. Available online: www.efsa.europa.eu

SUMMARY

Following a request from the European Commission, the Panel on Plant Health was asked to deliver a scientific opinion on a quantitative pathway analysis titled "Likelihood of Karnal bunt, (*Tilletia indica* M.), introduction as a result of the importation of United States (US) wheat for grain into the European Union and desert durum wheat for grain into Italy", made by the Animal and Plant Health Inspection Service of the United States Department of Agriculture (USDA APHIS). The analysis claimed that *T. indica* has an extremely low introduction potential in the European Union (EU) via the grain for consumption pathway.

The Panel was also requested to indicate whether or not the US bunted kernel standard, as used in the USDA APHIS quantitative pathway analysis, would provide an equivalent protection against the introduction of *T. indica* into the EU, compared to the existing EU import requirement. The US bunted kernel standard corresponds to the procedure described in the USDA APHIS Karnal bunt manual. The existing EU import requirements are listed in Annex I (A) (I) and in Annex IV, Part A, Section I of the Council Directive 2000/29/EC.

With regard to the scientific opinion on the USDA APHIS quantitative pathway analysis, the Panel followed a tiered approach, reviewing the pathway scenarios, the model and the parameters. Results of simulations and sensitivity analysis were also analysed by the Panel for both the importation of US wheat for grain into the EU and desert durum wheat for grain into Italy. The Panel found several shortcomings with respect to the model equations and parameter values:

- the entry of *T. indica* in Europe was considered by USDA APHIS to be uniform within a country. A mean value of teliospores on the soil surface was computed per hectare of wheat production. No consideration was given to literature on spatial aggregation of teliospores, in which some areas show values much higher and other areas much lower than the mean.

- the pathway analysis took into account overwintering survival of teliospores, which might add to the pool of teliospores the next season, but did not take into account teliospores produced *in situ* through the infection process and which might subsequently be air-dispersed.

- the pathway analysis did not consider the possibility that a single infected consignment could reach a specific location in Europe.

- the pathway analysis assumed that 150000 teliospores on the soil surface per hectare were required for introduction. This was based on a supposed inoculum threshold of 15 teliospores/m^2 for 1 bunted kernel/m^2 which was then scaled up by the factor 10^5 to give a threshold per hectare.

- there is no evidence for the existence of an infection threshold. The value given was based on a misunderstanding of a theoretical paper. There are no experimental data which support the existence of an infection threshold. One teliospore on germination can produce more than a hundred primary sporidia, which in turn produce secondary sporidia which infect the plant. Both mating types are produced from a single teliospore and hence new teliospores can be formed resulting in bunted kernels.

- several parameters of the model were inaccurately estimated.

The Panel analyzed two series of simulations:

i) simulations computed with the original USDA APHIS model for both the importation of US wheat for grain into the EU and the importation of desert durum wheat for grain into Italy,

ii) simulations computed with an updated version of the model based on the same equations but with parameter values modified according to the available literature and data.

These simulations were run for both the importation of US wheat for grain into the EU and the importation of desert durum wheat for grain into Italy. Both models were used to compute the number of teliospores per hectare on the soil surface of each country of the EU. In both models, it was assumed that the US bunted kernel standard was implemented to detect the presence of the disease in wheat grains produced in regulated counties. Simulated numbers of teliospores entering into the EU were lower with the updated version of the model than with the original version. However, both models showed that teliospores from *T. indica* could enter into EU and, consequently, that the US bunted kernel standard cannot be used alone to certify that grains exported from regulated counties are free from *T. indica*. These results showed that there is high uncertainty about the exact number of teliospores entering in each EU country and about the possibility of infection of European wheat from these teliospores due to lack of knowledge about key parameters and between year variability of wheat production and positive hectares in regulated counties. The uncertainty was underestimated with the original model.

The sensitivity analysis carried out by the Panel showed that several key parameters strongly influence the simulated number of teliospores entering into the EU. With all the four tested models, the most influential parameter was the proportion of kernels that are bunted in regulated counties of Arizona. The number of positive hectares in Arizona and the number of teliospores per bunted kernel were also systematically found among the parameters with the highest sensitivity indices. In addition to these three parameters, high sensitivity indices were obtained with the wheat for grain updated model for several parameters related to EU member state characteristics (probabilities of spilled teliospores being dispersed to wheat production areas, probability of teliospores released during milling being dispersed to wheat production areas, probability that wheat exported to EU member states is in a class grown in the US regulated areas, probability of manure being dispersed to wheat production area). Further research is needed to refine these parameter values and reduce the uncertainty about the simulated number of teliospores entering the EU. Further research is also needed to determine the relationship between teliospores number on the soil surface and the number of bunted kernels that result from infection of a wheat plant.

The USDA APHIS claimed that the probabilistic quantitative pathway analysis indicates that “the US bunted kernel standard adequately prevents the export of epidemiological significant levels of *T. indica* in US grain”. The Panel concluded that this claim could not be substantiated for the following reasons:

- epidemiological significance can only be judged in terms of the introduction potential of the organism into the EU territories.

- the quantitative pathway analysis (the original model and the updated versions considered in this opinion) predicted that teliospores enter the EU territories via the grain for consumption pathway.

- the numbers of teliospores on the soil surface could be converted to bunted kernels per hectare (using the USDA APHIS threshold assumption) but the numbers obtained would be very small in relation to the number of kernels produced per hectare of wheat. This would place major sampling constraints on observing the disease in the field.

- introduction depends on entry and establishment. The quantitative pathway analysis predicted that entry would occur but cannot be used to predict whether the organism will establish.

Therefore whether introduction is epidemiologically non-significant or is not could not be judged from the quantitative pathway analysis alone. More sophisticated epidemiological data collection and analysis would be required to make this judgement.

With regard to whether or not the US bunted kernel standard would provide an equivalent protection against the introduction of *T. indica* into the EU, compared to the existing EU import requirement, the Panel concluded that the US bunted kernel standard does not provide an equivalent level of protection to the EU requirements for the following reasons:

- the EU requires absence of the organism on grain, while the US bunted kernel standard tests for disease symptoms on grain (i.e. for bunted kernels). In the US bunted kernel standard, the presence of teliospores is tested only on the suspect bunted kernels in order to confirm the identification of the pathogen.

- the results of the simulations showed that, by applying the US bunted kernel standard, teliospores may enter the EU with grain imports.

- the US bunted kernel standard can detect diseased grain (bunted kernels) but not healthy grain carrying on its surface teliospores of the organism as contaminants.

- the US bunted kernel standard includes only one time of sampling and testing, at harvest, whereas the current EU requirements require one additional sampling and testing to be made before shipment.

Therefore, the Panel concluded that a level of protection comparable to the present EU requirement could only be warranted by measures which include testing at harvest and before shipment to detect teliospores both infecting and contaminating grain imported into the EU.

TABLE OF CONTENTS

BACKGROUND AS PROVIDED BY THE EUROPEAN COMMISSION[4]

The current Community plant health regime is established by Council Directive 2000/29/EC on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community (OJ L 169, 10.7.2000, p.1).

The Directive lays down, amongst others, the technical phytosanitary provisions to be met by plants and plant products and the control checks to be carried out at the place of origin on plants and plant products destined for the Community or to be moved within the Community, the list of harmful organisms whose introduction into or spread within the EU is prohibited and the control measures to be carried out at the outer border of the Community on arrival of plants and plant products.

In addition, the Directive provides that derogations may be granted with regard to requirements referred to in Annex IV, Part A, Section I. In such cases, the derogation has to set out specific alternative requirements to prohibit the introduction and spread of harmful organisms. The phytosanitary risk must be assessed on the basis of available scientific and technical information; where this is not possible it shall be supplemented by additional enquiries or investigations.

Tilletia indica Mitra is listed in the Annex I (A) (I) of Council Directive 2000/29/EC as a harmful organism of which introduction into or spread within the EU is prohibited. In addition, according to point 54 of Annex IV, Part A, Section I of the Council Directive 2000/29/EC, grain of the genera *Triticum*, *Secale* and × *Triticosecale* originating in the USA, must be accompanied by a phytosanitary certificate indicating that certain special requirements regarding the freedom from T. indica are fulfilled.

These requirements provide that the grain should originate either from a pest free area (PFA) where the organism is known not to occur or, if this is not feasible, from a place of production which is free from *T. indica*. The same requirement provides that the place of production freedom should be demonstrated by the absence of symptoms on plants during their last complete cycle of vegetation and the confirmed absence of the organism in the grain after appropriate sampling and testing at both time of harvest and before shipment. The compliance to one of these requirements i.e. origin from a PFA or the place of production freedom should be stated to the phytosanitary certificate accompanying the consignment.

Failing to confirm the complete absence of *T. indica* in certain areas of the US and pleading substantial and technical difficulties for the fulfilment of the freedom at harvest and prior to shipment requirement, the USDA developed a bunted kernel standard which supports that the absence of bunted kernel visual symptoms during the complete cycle of vegetation, could alone justify an epidemiologically non-significant, hence phytosanitary acceptable introduction potential of the organism.

For this reason the USDA submitted in 2009 a Quantitative Pathway Analysis with title "Likelihood of Karnal Bunt (*Tilletia indica* M.), introduction as a result of the importation of US wheat for grain into the EU and desert durum wheat for grain into Italy", supporting that *T. indica* has extremely low introduction potential in the EU via the grain for consumption pathway. The request is supported by a probabilistic model indicating that the US bunted kernel standard adequately prevents the export of epidemiologically significant levels of *T. indica* in US grain.

The Committee discussed the information provided and concluded that the technical justification included, moves to the opposite direction to the conclusions of an EU pest risk analysis (PRA) which was produced in 2006 (http://karnalpublic.pestrisk.net/). The PRA showed that the pathogen has the potential to enter into the EU if no appropriate preventive measures are implemented. In addition, the

---

[4] Submitted by the European Commission, ref. SANCO E1/DF/svi D(2009)510373

same PRA indicated that there is a considerable risk of Karnal Bunt establishment, which could have a serious impact for the wheat producing areas of the Community.

A scientific evaluation of the U.S. Quantitative Pathway Analysis is therefore needed.

TERMS OF REFERENCE AS PROVIDED BY THE EUROPEAN COMMISSION

EFSA is requested, pursuant to Article 29(1) and Article 22(5) of Regulation (EC) No 178/2002, to provide a scientific opinion on the Quantitative Pathway Analysis titled "Likelihood of Karnal Bunt, (*T. indica* M.), introduction as a result of the importation of US wheat for grain into the EU and desert durum wheat for grain into Italy", supporting that *T. indica* has extremely low introduction potential in the EU via the grain for consumption pathway.

EFSA is also requested to indicate whether or not the US bunted kernel standard would provide an equivalent protection against the introduction of *T. indica* into the EU, compared to the existing EU import requirement described above.

ASSESSMENT

1. Introduction

1.1. Karnal bunt: history and distribution

T. indica was first found in 1930 at Karnal, Haryana, in northern India (Mitra, 1931). It occurs in the northern part of India in the states of Delhi, Himalchel Pradesh, Madhya Pradesh, Jammu and Kashmir, West Bengal, Gujarat, Uttar Pradesh, Punjab, Rajasthan and Haryana. The pathogen has also been recorded in other Asian countries, including Pakistan, Afghanistan, Iraq, Nepal (Warham, 1986) and Iran (Torabi et al., 1996). *T. indica* was not identified outside Asia until 1972, when it was reported from the state of Sonora in northern Mexico (Durán, 1972; Sansford, 1998). At that time, the disease was restricted to the Yaqui and Mayo valleys in Sonora and was found in only trace amounts in farmers' fields (Rush et al., 2005). However, in the early 1980s, disease surveys in these valleys found Karnal bunt on 64 % of the farms (Rush et al., 2005). Karnal bunt was found in a seed sample in Arizona in early 1996 (Ykema et al. 1996), and subsequently bunted grains were detected in Arizona, California, New Mexico and Texas. As a result, the United States Department of Agriculture, Animal and Plant Health Inspection Service (hereinafter referred to as USDA APHIS), began surveying wheat producing areas in 1996 to determine the extent of Karnal bunt in the United States[5] (Ykema et al.,1996; Rush et al., 2005). Until now Karnal bunt disease of wheat has been detected in the US in counties of Arizona, California and Texas (Rush et al., 2005; USDA APHIS, 2008). *T. indica* was first reported from Brazil in 1993 in the southern part of the Rio Grande do Sul and efforts were made to eradicate it (Da Luz et al., 1993). However, no further information on its current status in Brazil has been found (Sansford et al., 2007). The first report of *T. indica* in South Africa was made in 2000 in the northern Cape Province (Crous et al., 2001) where it is thought to have been subject to eradication. However, since then it was found to have spread to a number of new areas in this country (Naudé, 2002).

1.2. Karnal bunt epidemiology

T. indica survives in the form of teliospores produced within sori on kernels by a teliosporogenous mycelium. Teliospores of *T. indica* are very resistant to adverse environmental conditions and have been reported to persist in soil for several years (Smiley, 1997; Chib et al., 1990; Krishna and Singh, 1983; Rattan and Aujla, 1990). Experimental results from the EC Fifth Framework Project QLK5-1999-01554: "Risks associated with *Tilletia indica*, the newly-listed EU quarantine pathogen, the cause of Karnal bunt of wheat" have shown that teliospores may survive for at least 3 years in soils in three locations in the European Union[6] (United Kingdom, Italy and Norway) at 5, 10 and 20 cm depths. Germinating teliospores produce promycelia (Mitra, 1931, Krishna and Singh, 1983, Warham, 1986) bearing primary sporidia in large numbers, with some variation according to the authors: 32-128 (Mitra, 1931), 26-171 (Holton, 1949), 50-140 or more (Durán, 1972). Primary sporidia germinate to produce hyphae or sterigmata on which secondary sporidia are formed and forcibly discharged (Agarwal et al., 1993; Warham, 1986). Secondary sporidia produce hyphae or other sporidia by repetition (Fuentes-Dávila et al., 2002).

Sporidia may land on and infect susceptible hosts during a period of favourable environmental conditions. European wheat cultivars are susceptible to infection and further disease development under European climatic conditions (Riccioni et al., 2008). Data indicate that the potential geographic range for Karnal bunt is restricted less by physical requirements for survival of *T. indica* teliospores than by synchronisation of wheat heading with climatic conditions favourable for teliospore germination, secondary sporidial multiplication, host penetration and infection (Smiley, 1997). Humidity at the time of heading appears to be the most important environmental factor for Karnal bunt occurrence (Aujla et al., 1977; Singh and Prasad, 1978; Warham and Flores, 1988). The above

---

[5] Hereinafter referred to as US.

[6] Hereinafter referred to as EU

mentioned research project (Sansford et al., 2006) studied the establishment potential of *T. indica* in the EU territory by adopting an approach combining a pathogen model with crop phenology models. This combined modelling approach was deployed to identify if overlap occurs between the susceptible phenological stage of wheat and the meteorological conditions suitable for *T. indica* infection and disease development. The results from the study was that there is a substantial risk of infection by *T. indica* in most years in the EU for both durum and bread wheat. The risk is not greatly influenced by the management of the crops in terms of sowing date or maturity class. Climatic variation at the continental European scale is a strong determinant of the risk of establishment of *T. indica*. Northern regions may on occasion be too cold and western regions too moist to favour infection and disease development. However, using historic meteorological data on a year by year basis, there were always years and locations in Europe shown to be favourable to infection and disease development.

There is no information available in the literature either on the minimum density of teliospores in soil or on the number of sporidia at the infection court that are necessary for the Karnal bunt symptoms on wheat plants, or whether such thresholds exist. According to Rush et al. (2005), the relationship between inoculum density and disease incidence has yet to be elucidated. Studies in Arizona attempting to determine the minimum teliospore threshold required for infection have been unsuccessful to date because of the lack of suitable environmental conditions, even in the presence of a misting system (Rush et al., 2005).

Disease severity on individual kernels varies from small points of infection at the embryonic end (tip-infection; according to Nagarajan, 2001, this is a type 1 sorus) to complete transformation of the kernel into a sorus (sorus type 4) (Cunfer et al., 1997; Fuentes-Dávila, 1997; Nagarajan, 2001). The weight of infected grain is directly related to the severity of infection. As the amount of infection increases, the grain weight correspondingly decreases (Bedi and Meeta, 1981; Bedi et al., 1981; Rai and Singh, 1982). The difference in weight between heavily and slightly infected grains can be about 50 % (Bhat et al., 1980). Similarly Bansal et al. (1984a, in Warham, 1986) found that an increase in disease severity proportionately decreased the 1,000 grain weight of four different wheat cultivars. At low disease severities, losses were greatest in the cultivar with the smallest grains. *T. indica* reduces flour quality in terms of colour, odour and palatability. There appears to be some controversy on the level of infection that affects flour quality. According to Vimal Mehdi et al. (1973), 1-3 % infected kernels may be sufficient to render wheat grain unacceptable for human consumption. Other researchers, however, tend to agree that with 3 % or less infected kernels the quality characteristics such as appearance and palatability for bread are unaffected (Sekhon et al., 1980). Grain with 5 % infected kernels can be used to produce satisfactory products if they are first washed, whereas if they are washed and steeped, samples with 10 % infected grains can be used to produce acceptable products (Sekhon et al., 1981). According to Peña et al. (1992), in general, levels of infection of up to 9 % do not influence negatively the milling and baking quality characteristics of wheat. In addition, flour and bread samples are organoleptically acceptable at 1-3 % infection level, respectively. The same authors concluded that washing prior to milling make it possible to produce flour and bread having acceptable organoleptic characteristics from wheat lots with up to 6 % infection.

1.3. Wheat production in the US states where Karnal bunt has been detected

Karnal bunt disease of wheat has been reported in US in counties of Arizona, California and Texas. There was an initial report also from New Mexico counties where Karnal bunt infested seed was used for planting, but subsequently symptoms of the disease have never been observed in this state (Rush et al., 2005).

In 2009, Arizona, California and Texas together accounted for approximately 6 % of the total US wheat harvested area and 5 % of total US wheat production. Among these three states, Texas is the major producer with 4.9 % of the total US wheat harvested areas and 2.8 % of total US wheat production. The states of Arizona and California, respectively, accounted for 5 % and 7 % of total US durum wheat harvested area and for 11 % and 16 % of total US durum wheat production in 2009 (USDA NASS, online). A large proportion of the durum wheat grown in these states is "DesertDurum®", a registered brand name for durum wheat grown in Arizona and California. Desert durum wheat is produced under irrigation in the desert valleys and lowlands of Arizona and California, in regions of high temperatures (May-June temperatures average 32 °C) and low rainfall (annual precipitation averages less than 200 mm). Desert durum wheat is planted in December through February and harvested in May and June with an average grain moisture content of 6-7 %. Due to its low moisture, large uniform kernels and high gluten strength, Desert durum wheat is appreciated by millers and pasta manufacturers (DesertDurum®.com, online; Posner et al., 2006). Desert durum wheat is usually delivered "identity preserved" to US domestic and export markets. The identity preservation system allows buyers to purchase grain of varieties having intrinsic quality parameters specific to their needs. Annual production requirements are contracted in advance to growers using certified seed, and then stored by identity for season-long shipment at the buyer's schedule. Desert durum is handled by a limited number of grain merchandisers (four in Arizona and four in California) and mostly shipped from US ports on the Gulf of Mexico (DesertDurum®.com, online). In most years, more than 60 % of the total production of desert durum wheat is exported, Italy being the main importer country (Arizona Grain Research and Promotion Council, 2005, 2006, 2008).

1.4. European Union wheat grain production, import and milling

Harvested production, area of production (Eurostat, online a) and imported quantities (Eurostat, online b) for common wheat (or bread wheat, *Triticum aestivum* L.) are shown (together with spelt) for the EU Member States in tables 24, 26 and 28 in Appendix A of this opinion. The highest harvested productions of common wheat are reported for France, Germany and United Kingdom (table 24) and the highest areas of production for France, Germany and Poland (table 28). Among EU member states, the main importers of common wheat and spelt in the EU are Spain, Italy and United Kingdom (table 26). The European flour milling industry, with more than 3000 milling companies processes annually about 45 million tonnes of wheat and rye, mostly from intra-EU origins and partly (about 2.5 million tonnes of hard red spring wheat) from third countries such as US and Canada (GAM, 2008; European Flour Millers, online).

The production of durum wheat (*Triticum durum*), used for production of pasta, couscous and bread in the European Union, varied in the period 2000-2009 between 8 and 12 million tonnes, with Italy, France, Spain and Greece being the top producers in terms of harvested production and area of production (table 25 and table 29). The importation of durum wheat grain varied in the same period between 1 and 2 million tonnes per year, with Italy being the main importer of durum wheat (Table 27). The EU durum wheat semolina industry is based on 210 mills, about 160 of which are located in Italy; these mills process 7.5 million tonnes of durum wheat yearly for the production of more than 5 million tonnes of durum wheat semolina, essentially for use by the pasta industry (Italmopa, online; Semouliers, online).

1.5. Structure of the opinion

Following this introduction, the scientific opinion is structured in two main parts.

Section 2 answers the first question of the terms of reference, i.e. the evaluation of the USDA APHIS quantitative pathway analysis, is dealt with in Section 2.

The second question of the terms of reference, i.e. whether or not the US bunted kernel standard would provide an equivalent protection against the introduction of *T. indica* into the EU, compared to the existing EU import requirement, is dealt with in Section 3.

2. Review of the USDA APHIS quantitative pathway analysis

The USDA APHIS quantitative pathway analysis is based on two models, one for the wheat pathway (both common and durum wheat), and one for the desert durum wheat pathway. The methods used for evaluating the two models are presented in Section 2.1 and the results of the evaluation are presented in Section 2.2. Scenario, model assumptions and structure, parameter values are reviewed by the Panel in Sections 2.2.1, 2.2.2, 2.2.3, and 2.2.4. The outputs obtained with the original versions of the two models are presented and discussed in Section 2.2.5. Updated versions of the wheat and desert durum models are then defined in Section 2.2.6 based on available data and literature, and the outputs of the two updated models are presented and discussed in Section 2.2.7. Finally, conclusions are presented in Section 2.3 based on both the original and updated versions of the wheat and desert durum models.

A detailed description of the simulation results is presented in a separate technical report of EFSA (EFSA, 2010).

2.1. Methods for evaluation of the USDA APHIS document

Review of probabilistic models has been made by many authors, e.g. Morgan and Henrion (1990). Several problems are noted arising from the need for a complete documentation of the model and all data sources, the complexity of the model, its implementation, and the involvement of experts from several disciplines.

Morgan and Henrion (1990) describe the process as:

"For a complex policy model, a thorough review can be an extremely arduous and time consuming business, even if adequate documentation exists. Such review is far from standard practice (von Hippel, 1981).(...) There is increasing interest in the problems and practice of model assessment (NBS, 1980). It has been suggested (GAO, 1979) that model assessment should include examination of all data, assumptions, and computer code, with additional runs of the model to examine sensitivities. Models are often assembled by a team of specialists from several different disciplines (e.g., economists, natural scientists, engineers, statisticians, computer specialists, etc.). It is unrealistic to expect a reviewer to be able to perform a complete assessment, unpaid and single-handed. In the case of large models, a proper external assessment will require a multidisciplinary team, and a significant budget. (...) Many practitioners in policy analysis have argued that peer reviewed publication is not appropriate to the field, an argument sometimes made even in the case of modest analyses that do not involve large complex models. The claim is that peer review is not feasible because of the time urgent nature of the work." (ibidem, *chapter 3.2.4).*

Nevertheless a thorough review is recommended to establish an appropriate degree of confidence in the results and the decisions that follow in view of the identified uncertainties and data gaps.

Whereas guidance on systematic review of probabilistic models is missing, the "Project on the Harmonization of Approaches to the Assessment of Risk from Exposure to Chemicals (Harmonization Project)" of the International Programme on Chemical Safety (IPCS) and the World Health Organization (WHO) developed guidance on characterizing and communicating uncertainty in exposure assessment (WHO/ICPS, 2008). Here it is recommended: *"The results of the assessment should be subject to an evaluation process that may include peer review, model comparison, quality assurance, or comparison to relevant data or independent observations."* (ibidem, *Recommendation 8)*

The WHO/IPCS (2008) report describes existing concepts for a systematic assessment of uncertainties and proposes a harmonized approach for a qualitative analysis. In this document the structure will be used as guidance for a systematic evaluation of an existing report.

"The objective of qualitative characterization of uncertainty includes transparency in identifying key sources of uncertainty as an aid to risk managers who may need to make decisions in the absence of extensive data sets for substances with limited information - a prerequisite to quantification of uncertainty for substances with more extensive data.

The aim of qualitative characterization of uncertainty is to provide a conceptual basis for the systematic assessment of uncertainty in decision support processes such as exposure assessment. It focuses on uncertainty perceived from the point of view of assessors providing information to support policy decisions - that is, uncertainty regarding the analytical outcomes and conclusions of the exposure assessment." (WHO/IPCS, 2008, p.38)

This approach exceeds in some respects the proposal for a qualitative analysis (Tier 1) formulated in a previous EFSA Guidance on “Uncertainties in Dietary Exposure Assessment” (EFSA, 2006); but the PLH Panel selected the WHO/IPCS approach due to the specific terms of references, which ask for a qualitative and as well a quantitative review of the existing quantitative, probabilistic pathway model. The necessity to review all quantitative elements requires also a more detailed qualitative analysis of the model.

The WHO/IPCS approach consists of two basic steps:

1. the specification of all sources of uncertainty, and
2. the qualitative characterization.

The Panel added the review of the quantitative characterization in the second step.

The specification of sources of uncertainty focuses on the main classes of uncertainty: scenario uncertainty, model uncertainty and parameter uncertainty. The relating parts of the exposure assessment: scenario definition, model definition and parameter definition can also be seen as a tiered approach in the modelling procedure. Each step defines a further refinement of specifications, including additional gaps in information and uncertainties.

The first tier of the evaluation procedure analyses the definition of the general scenario. Uncertainties are discussed in terms of:

- Basic source : scenario
    - Source and target population of the agent, exposure pathways
    - Exposure routes, events
    - Spatial and temporal resolution, microenvironment
    - Variation in agent, exposed population, time and space, activities
    - Risk management options

The second tier looks on the definition of the model. This includes uncertainties in the “conceptual model”, which connect the selected scenario with the concrete quantitative computations.

- Basic source : model
    - Model assumptions, structure and dependencies
    - Model complexity and equation
    - Extra- and interpolation by the model
    - Model implementation (software)

The third tier assesses the quantitative parameters and describes their parameter uncertainties:

- Basic source : parameters
    - Data sources, correlation and precision
    - Data quality, use substitutions or expert judgement
    - Selection or estimation of concrete values or distributions
    - Division in variation and uncertainties

For all identified sources of uncertainty the qualitative evaluation

1. discusses the level of uncertainty;
2. qualitatively evaluates the appraisal of the knowledge base of each major source;
3. determines the controversial sources of uncertainty and qualitatively evaluates the subjectivity of choices in each controversial source.

The level of uncertainty describes the overall impact of the uncertainty on the output of the model. In a quantitative analysis this can be done by a sensitivity analysis, as performed in this report.

Table 1: The appraisal of the knowledge base focuses on the adequacy of the available knowledge base for the assessment (WHO/IPCS, 2008, Table 2)

Criteria	**Approaches and considerations**
Accuracy	1) establishing the knowledge base needed to obtain answers of the required quality
	2) signalling controversies with respect to the knowledge base
	3) identifying the most important bottlenecks in the available knowledge
	4) determining the impact of these bottlenecks on the quality of the results
	5) assessing the assumptions covering the knowledge gaps
Reliability	1) criticizing the knowledge base severely on factual and methodological grounds
	2) identifying the scientific status of the knowledge base
	3) determining the quality soundness of the knowledge base
	4) assessing the appropriateness of judgemental estimates of level of confidence
Plausibility	1) determining the completeness of the knowledge base
	2) acknowledging ignorance when applicable
	3) analysing the possibility of changes in underlying processes over time
	4) considering well established observations
Scientific consistency	1) assessing the consistency of scientific support
	2) assessing the maturity of the underlying science
	3) assessing the scientific limitations
	4) analysing the degree to which understanding is based on fundamental concepts tested in other areas
Robustness	1) assessing the predictability of the values and of the results
	2) assessing the dependency relationships

The subjectivity of choices delivers insight into the decision process of the assessors.

Table 2: Subjectivity of choice (WHO/IPCS, 2008, Table 3)

Criteria	Approaches and considerations
Choice space	1. spanning alternative choices
Intersubjectivity among peers and among stakeholders	2. specifying the similarity of choices among peers and among stakeholders
	3. specifying the controversy of choices among peers and among stakeholders
Influence of situational limitations (e.g.	4. determining the influence of situational limitations on the

money, tools and time) on choices		choices
Sensitivity of choices to the analysts' interests	5.	assessing the sensitivity of the choices to the analysts' interests
Influence of choices on results	6.	determining the influence of the choices on the results

2.2. Results of the evaluation of the USDA APHIS document

In this Section, we review the scenario (2.2.1), model assumptions and structure (2.2.2), wheat model parameter values (2.2.3), and desert durum wheat model parameter values (2.2.4). Parameter values are presented and discussed submodel per submodel. Model outputs obtained with the original models are presented in 2.2.5.1 and the sensitivity of model outputs to parameter values is analyzed in 2.2.5.2. Updated versions of the models are then defined in 2.2.6.1 and 2.2.6.2 for the wheat model and for the desert durum wheat model respectively. Their outputs are presented in 2.2.7.1 and the sensitivity of these outputs to parameter values is analyzed in 2.2.7.2.

2.2.1. Scenario considered by the USDA APHIS quantitative pathway analysis

The evaluation of the USDA APHIS document follows the tiered approach discussed on Section 2.1. The main tiers are the review of the pathway scenarios, the model and the parameters.

2.2.1.1. Pathways

Two pathway scenarios are considered in the USDA APHIS quantitative model:

- introduction of *T. indica* in each EU country from the importation of US wheat for grain
- introduction of *T. indica* in Italy from the importation of US desert durum wheat for grain

These pathways only consider the importation of wheat and desert durum wheat from US for the European and Italian milling industry. It is assumed that no grain would be diverted for seeds. It is also assumed that whole grain for feed would not present a pathway for *T. indica* introduction, considering that sample grade grain, e.g. low quality wheat grain, is typically blended with other wheat to produce flour rather than being sent directly to feedlots. No consideration is given to the pathway of grain for ethanol. This leads to uncertainty as this pathway is not discussed and data on its possible importance are not provided.

As the reason of the quantitative pathway analysis is to ask for a derogation for the importation of wheat and desert durum wheat for grain, other potential pathways of introduction are not considered in the USDA APHIS document (e.g., straw, machinery, and travelers which are considered as potential pathways of introduction of *T. indica* in Australia by Stansbury et al. (2002)).

2.2.1.2. Space scale

The areas of wheat production in the US considered in the model are:

- Karnal bunt regulated counties of Arizona, California and Texas, for the wheat for grain pathway (Table 3)
- Karnal bunt regulated counties of Arizona and California, for the desert durum wheat for grain pathway (Table 3)

The risk of *T. indica* introduction from the wheat for grain pathway is computed by the model for each EU country separately. The risk of *T. indica* introduction from the desert durum wheat pathway is computed for Italy only.

Table 3: Karnal bunt regulated counties of Arizona, California and Texas (1 = regulated; 0= non regulated) 1997-2008 (from USDA APHIS Central Federal Registry Ch. III Subpart –Karnal bunt 301.89 editions 1997-2009)

	State	AZ	AZ	AZ	AZ	CA	CA	TX	TX	TX	TX	TX	TX	TX	TX	TX	TX
Year	County	Lapaz	Maricopa	Pinal	Yuma	Imperial	Riverside	Archer	Baylor	El Paso	Hudspeth	Knox	McCulloch	Mills	San Saba	Throckmorton	Young
1997		1	1	1	1	1	1	0	0	1	1	0	1	1	1	0	0
1998		1	1	1	1	1	1	0	0	1	1	0	1	1	1	0	0
1999		1	1	1	1	1	1	0	0	1	1	0	1	0	1	0	0
2000		1	1	1	1	1	1	0	0	1	1	0	1	0	1	0	0
2001		1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1
2002		1	1	1	0	1	1	1	1	0	0	1	1	0	1	1	1
2003		1	1	1	0	1	1	1	1	0	0	1	1	0	1	1	1
2004		1	1	1	0	1	1	1	1	0	0	1	1	0	1	1	1
2005		1	1	1	0	0	1	1	1	0	0	1	1	0	1	1	1
2006		1	1	1	0	0	1	0	1	0	0	1	0	0	0	1	1
2007		1	1	1	0	0	1	0	1	0	0	1	0	0	0	1	1
2008		1	1	1	0	0	1	0	0	0	0	0	0	0	0	1	1

AZ = Arizona, CA= California, TX=Texas

Within-country variability is not considered by the model and thus the level of risk is considered to be constant within each country

2.2.1.3. Time-frame

Teliospore accumulation is computed for each EU country over a five year period. Recent empirical data from different years are used to describe the actual situation and predict the effect of the application of the USDA APHIS bunted kernel standard (e.g., Rush et al., 2005; USDA APHIS, 2007).

2.2.1.4. Detection method

The detection method considered by the model corresponds to the USDA APHIS bunted kernel standard (e.g., Rush et al., 2005; USDA APHIS, 2007). The model thus assumes that every field in regulated counties is checked for the presence of bunted kernels by manual inspection in Arizona and California, and by using a high speed optical sorter in Texas. Under the scenario considered by the model, grains are not tested for the presence of the pathogen

2.2.1.5. Variation

Several sources of variation are taken into account by the model:

- Variability of the wheat production between counties and between years
- Variability of the proportion of the regulated counties that are positive for bunted kernels
- Proportion of bunted kernels in bunted kernel positive areas
- Bunted kernels exported to each EU country
- Total, agricultural land and wheat cultivated areas in each EU country and their variability across years

Several potential sources of variation are not taken into account by the original USDA APHIS model:

- wheat cultivars (e.g., potential yields, susceptibility to *T. indica*)
- characteristics of the condition of transportation between ships and storage units, and between storage units and mills (e.g., grain unload technique, distances)
- characteristics of the mills (e.g. size)
- variability of teliospore density between different sites located within a given EU country

2.2.2. Model assumptions, dependency (interaction of input parameters) and structure

The model follows the pathway of teliospores of *T. indica* from their appearance on infected fields of wheat production in the regulated counties in the US States of Arizona, California and Texas to their dispersal on wheat growing areas in European countries.

The starting point is the yield of wheat or durum wheat and its infestation with bunted kernels in the years 1997-2005. The end-point variable is the average number of viable teliospores per hectare of wheat production area with suitable temperatures for T. indica introduction. The calculation is made for each European country separately.

The risk (probability) of introduction is estimated by applying a minimal threshold value to the average teliospore density per hectare. The risk is calculated for the first year after applying the US bunted kernel standard and for the accumulated values in the following four years. Furthermore, the time needed for introduction is calculated by a negative binomial distribution.

A probabilistic approach is used to calculate the variation between years and the uncertainty of introduction, by calculating confidence limits for introduction under varying and uncertain conditions.

Figure 1: Grain pathway model (from USDA APHIS, 2008)

The full model is divided into five separate sub models:

1. Grain export sub-pathway model
2. Wheat for flour sub-pathway model
3. Millfeed products sub-pathway model
4. Spillage sub-pathway model
5. *T. indica* introduction sub-pathway model

Each preceding model ends with the number of bunted kernels or teliospores and their probability to enter the next step. The number entering the proceeding step is determined by a binomial experiment giving additional variation of the outcome variable.

2.2.2.1. Submodel 1 – Grain export sub-pathway model

The first submodel describes the total number of bunted kernels exported by the US.

This number is estimated by the yearly yield from the affected counties for each State (index a) separately, expressed in numbers of bushels per year (W_a), converted by weight (by a factor U_w) and number of kernels produced (factor $U_{bunt,a}$). The weight per bushel (U_w) is assumed to be constant.

To obtain the number of bunted kernel per State several correction factors are applied. These are the ratio of positive and harvested hectares in the specific county ($A_{pos,a}/A_a$), the proportion of bunted kernels on positive fields ($Q_{bunt,a}$), the proportion of bunted kernels which escape detection ($Q_{nondet,a}$) and the proportion of bunted kernels exported ($Q_{exp,a}$). Intermediate calculations of numbers of kernels are rounded to the next integer.

The final number of exported bunted kernels ($B_{exp,a}$) is the sum of the numbers exported from Arizona, California and Texas for wheat or from Arizona and California for desert durum wheat.

All input variables were modelled by distributions to express their variation and/or uncertainty and assumed to be independent.

Table 4: Grain export sub-pathway (Steps 1 to 11)

Name of input variable	Symbol	Unit
index of affected counties	a	#
bushels/yr of kernels from the affected county	W_a	[1/y]
kg per bushel	U_w	[kg]
positive hectares	$A_{pos,a}$	[ha]
harvested hectares	A_a	[ha]
proportion that are bunted kernels	$Q_{bunt,a}$	[-]
bunted kernels per kg (kernels per kg bunted kernels)	$U_{bunt,a}$	[1/kg]
proportion of bunted kernels escape detection by PPQ	$Q_{nondet,a}$	[-]
proportion of bunted kernels exported	$Q_{exp,a}$	[-]
Name of output variable		
total bunted kernels exported	$B_{exp,a}$	[1/y]

$$B_{exp} = \sum_{a=1}^{3} \left[W_a \cdot U_w \cdot \frac{A_{pos,a}}{A_a} \cdot Q_{bunt,a} \cdot C_{bunt,a} \cdot Q_{non\,det,a} \cdot Q_{exp,a} \right] \qquad \text{(Eq. 1)}$$

2.2.2.2. Submodel 2 – Wheat for flour

The first part of the second submodel calculates the number of bunted kernels exported to a specific country of the European Community (index i). As a simplification, Luxemburg is modelled in combination with Belgium.

As intermediate results, two probabilities were estimated. The probability that an exported kernel arrives at one specific EU country $P_{part,i}$ is estimated by the ratio of total amount of USA exported wheat to a specific country divided by the total amount of US exported wheat to the whole world. This calculation assumes that produced kernels of US export will be homogeneously distributed to all countries.

A second probability $P_{class.i}$,that an imported kernel in one Member State is of an affected wheat class, is estimated by the ratio of the total number of imported metric tons of this class divided by the total number of imported kernels of all classes. This calculation assumes that the kernels of affected classes are not traceable in the importing country.

Both probabilities are multiplied, which expresses the independency of each process. In summary, it means that each imported kernel has the same chance to be produced in the regulated US area and each produced kernel of the whole US production has the same chance to reach a specific European country. Economic relationships, such as the export of a specific variety (e.g. desert durum) or from a specific production area to a specific country or importer (e.g. Italian pasta producer), does not fit into this assumption. Therefore, a second scenario was defined by USDA APHIS resulting in specific parameters for the specific desert durum wheat pathway for Italy, while the model equations were not changed.

An error term ε_i adds variation which results from the individual distribution of the bunted kernels exported to each country, expressed through the asymptotic normal distribution of a binomial experiment.

Table 5: Wheat for flour sub-pathway (Steps 1 to 4)

Name of input variable	Symbol	Unit
index of import EU country	i	#
probability bunted kernels exported to EU country	$P_{part,i}$	[-]
probability exported wheat is a class grown in the US regulated areas	$P_{class,i}$	[-]
Name of output variable		
high precision probability bunted kernels exported to EU country	$P_{import,i}$	[-]
bunted kernels exported to EU country	$B_{bunt,i}$	[-]
additional error	ε_i	[-]

$$P_{import,i} = P_{part,i} \cdot P_{class,i} \qquad \text{(Eq. 2)}$$

$$B_{bunt,i} = B_{exp} \cdot P_{import,i} + \varepsilon_i \qquad \text{(Eq. 3)}$$

with additional error

$$\varepsilon_i \approx \text{Normal}(0, B_{exp} \cdot P_{import,i} \cdot (1 - P_{import,i})) \qquad \text{(Eq. 4)}$$

The result is rounded to the next full number and truncated below zero.

In the next step the number of bunted kernels $B_{bunt,I}$ is converted to the number of released teliospores by a conversion factor T_{bunt}.

There are several routes included in the model as to how *T. indica* teliospores can reach European wheat fields:

I. Spillage between port and storage unit

II. Spillage between storage and mills

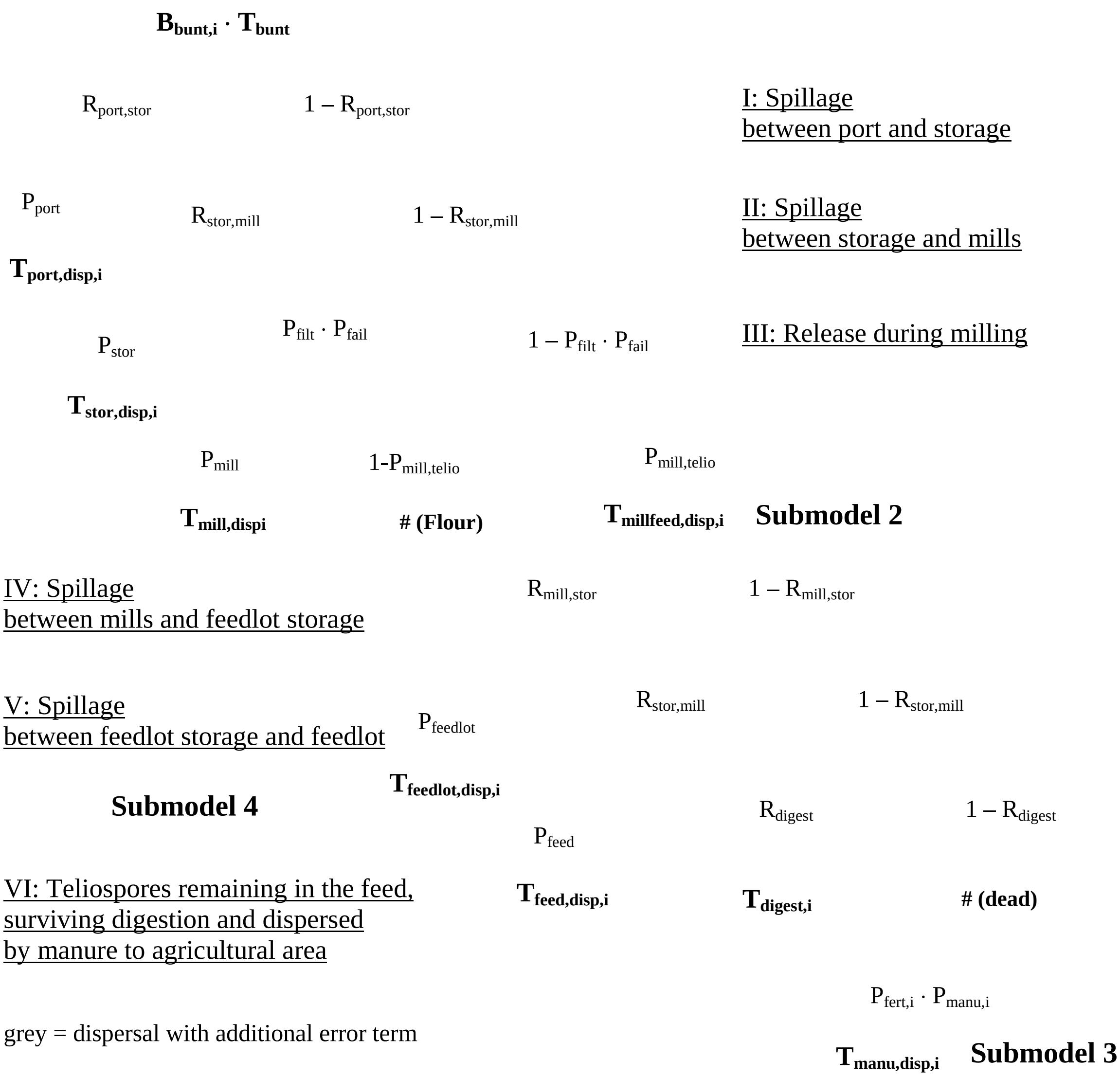
III. Release during milling

IV. Teliospores remaining in the feed and spilled between mills and feedlot storage

V. Teliospores remaining in the feed spilled between feedlot storage and feedlot

VI. Teliospores remaining in the feed, surviving digestion and dispersed by manure to agricultural areas

Figure 2: Routes from import to wheat production area



grey = dispersal with additional error term

The number of teliospores remaining in products for feed $T_{millfeed,i}$ (route VI) needs information on the loss between port and storage $R_{port,stor}$, between storage and mill $R_{stor,mill}$, the probability that teliospores are trapped by the filter system P_{filt}, the probability that the filter system is not working P_{fail} and the proportion of milling products going to feed $P_{telio,mill}$.

Table 6: Wheat for flour sub-pathway (Steps 5 to 15)

Name of input variable	**Symbol**	**Unit**
teliospores per bunted kernel	T_{bunt}	[-]
proportion of teliospores spilled from port to storage processing facility	$R_{port,stor}$	[-]
proportion of teliospores spilled from storage to mill processing facility	$R_{stor,mill}$	[-]
probability teliospores enter house filter	P_{filt}	[-]
probability house filter fails	P_{fail}	[-]
probability teliospores in millfeed	$P_{telio,mill}$	[-]
Name of output variable		
teliospores at mills after milling	$T_{mill,i}$	[-]
teliospores sent to millfeed	$T_{millfeed,i}$	[-]
additional error	$\varepsilon_{millfeed,i}$	[-]

$$T_{mill,i} = B_{bunt,i} \cdot T_{bunt} \cdot (1 - R_{port,stor}) \cdot (1 - R_{stor,mill}) \cdot (1 - P_{filt} \cdot P_{fail}) \qquad \text{(Eq. 5)}$$

The error term $\varepsilon_{millfeed,i}$ adds variation which results from the individual distribution of the teliospores to the millfeed, expressed through the asymptotic normal distribution of a binomial experiment.

$$T_{millfeed,i} = T_{mill,i} \cdot P_{telio,mill} + \varepsilon_{millfeed,i} \qquad \text{(Eq. 6)}$$

with additional error

$$\varepsilon_{millfeed,i} \approx \text{Normal}(0, T_{mill,i} \cdot P_{telio,mill} \cdot (1 - P_{telio,mill})) \qquad \text{(Eq. 7)}$$

The result is again rounded to the next full number and truncated below zero.

2.2.2.3. Submodel 3 – Millfeed products

The teliospores in feed have to survive digestion R_{digest}, must be spread via manure $P_{fert,i}$ to reach an agricultural area, and then reach a wheat field with probability $P_{manu,i}$. The last probability is estimated by the ratio of area used for wheat production divided through the total agricultural area of each country.

Table 7: Millfeed products sub-pathway (Steps 1 to 10)

Name of input variable	**Symbol**	**Unit**
proportion of teliospores spilled from mill to feedlot storage	$R_{mill,stor}$	[-]
proportion of teliospores spilled from storage to feedlot storage	$R_{stor,feed}$	[-]
proportion teliospores that survive cattle digestion	R_{digest}	[-]
Probability manure dispersed to wheat production area	$P_{manu,i}$	[-]
probability feed lot manure used as fertilizer	P_{fert}	[-]
Name of output variable		
teliospores surviving digestion	$T_{digest,i}$	[-]
teliospores dispersed to wheat production area in manure	$T_{manu,disp,i}$	[-]
additional error	$\varepsilon_{manu,i}$	[-]

$$T_{digest,i} = T_{millfeed,disp,i} \cdot (1 - R_{mill,stor}) \cdot (1 - R_{stor,feed}) \cdot R_{digest} \qquad \text{(Eq. 8)}$$

The error term $\varepsilon_{manu,i}$ adds variation which results from the individual distribution of the teliospores to the wheat fields, expressed through the asymptotic normal distribution of a binomial experiment.

$$T_{manu,disp,i} = T_{digest,i} \cdot P_{manu,i} \cdot P_{fert} + \varepsilon_{manu,i} \qquad \text{(Eq. 9)}$$

with additional error

$$\varepsilon_{manu,i} \approx \mathrm{Normal}(0, T_{digest,i} \cdot P_{manu,i} \cdot P_{fert} \cdot (1 - P_{manu,i} \cdot P_{fert})) \qquad \text{(Eq. 10)}$$

The result is rounded to the next full number and truncated below zero.

2.2.2.4. Submodel 4 - Spillage

The pathways of spillage are each modelled in a similar way. To calculate the amount of spilled teliospores, the actual number before this step is needed, the proportion of teliospores spilled in this step, and the probability that spilled teliospores reach a wheat field. The last probability is estimated by the ratio of area used for wheat production divided through the total area of each country.

At the port all imported teliospores $B_{bunt,i} \cdot T_{bunt}$ are still present. The spilled part is $R_{port,stor}$ and the probability to reach a wheat production area is $P_{port,i}$.

Table 8: Spillage sub-pathway (Steps 1 to 2: spills during grain transport)

Name of input variable	Symbol	Unit
probability spilled teliospores from port to grain storage dispersed to EU wheat production area	$P_{port,i}$	[-]
Name of output variable		
spilled teliospores from port to grain storage	$T_{port,i}$	[-]
spilled teliospores from port to grain storage dispersed to EU wheat production area	$T_{port,disp,i}$	[-]
additional error	$\varepsilon_{port,i}$	[-]

$$T_{port,i} = B_{bunt,i} \cdot T_{bunt} \cdot R_{port,stor} \qquad \text{(Eq. 11)}$$

The error term $\varepsilon_{port,i}$ adds variation which results from the individual distribution of the teliospores to the wheat fields, expressed through the asymptotic normal distribution of a binomial experiment.

$$T_{port,disp,i} \approx T_{port,i} \cdot P_{port,i} + \varepsilon_{port,i} \qquad \text{(Eq. 12)}$$

with additional error

$$\varepsilon_{port,i} \approx \mathrm{Normal}(0, T_{port,i} \cdot P_{port,i} \cdot (1 - P_{port,i})) \qquad \text{(Eq. 13)}$$

The result is rounded to the next full number and truncated below zero.

Table 9: Spillage sub-pathway (Steps 1 to 2: spills during grain transport between grain storage and mills)

Name of input variable	**Symbol**	**Unit**
probability spilled teliospores between grain storage and mills dispersed to wheat production area	$P_{stor,i}$	[-]
Name of output variable		
spilled teliospores between grain storage and mills	$T_{stor,i}$	[-]
spilled teliospores between grain storage and millsdispersed to wheat production area	$T_{stor,disp,i}$	[-]
additional error	$\varepsilon_{stor,i}$	[-]

At storage some teliospores $B_{bunt,i} \cdot T_{bunt} \cdot (1-R_{port,stor,i})$ are still present. The newly, spilled part is $R_{stor,mill}$ and the probability to reach a wheat production area is $P_{stor,i}$. The last probability is estimated by the ratio of area used for wheat production divided through by the total agricultural area of each country.

$$T_{stor,i} = B_{bunt,i} \cdot T_{bunt} \cdot (1 - R_{port,stor}) \cdot R_{stor,mill} \quad \text{(Eq. 14)}$$

The error term $\varepsilon_{stor,i}$ adds variation which results from the individual distribution of the teliospores to the wheat fields, expressed through the asymptotic normal distribution of a binomial experiment.

$$T_{stor,disp,i} = T_{stor,i} \cdot P_{stor,i} + \varepsilon_{stor,i} \quad \text{(Eq. 15)}$$

$$\varepsilon_{stor,i} \approx \mathrm{Normal}(0, T_{stor,i} \cdot P_{stor,i} \cdot (1 - P_{stor,i})) \quad \text{(Eq. 16)}$$

The result is rounded to the next full number and truncated below zero.

Table 10: Spillage sub-pathway (Steps 1 to 2: teliospores released during milling)

Name of input variable	**Symbol**	**Unit**
probability teliospores released during milling dispersed to wheat production area	$P_{mill,i}$	[-]
Name of output variable		
spilled teliospores during milling	$T_{mill,i}$	[-]
spilled teliospores during milling dispersed to wheat production area	$T_{mill,disp,i}$	[-]
additional error	$\varepsilon_{mill,i}$	[-]

At the mill some teliospores $B_{bunt,i} \cdot T_{bunt} \cdot (1-R_{port,stor,i}) \cdot (1-R_{stor,,mill,i})$ are still present. The newly, spilled part are the teliospores entering the filter system of the mill P_{filt}, but which are not trapped P_{fail}, and the probability to reach a wheat production area $P_{mill,i}$. The last probability is estimated by the ratio of area used for wheat production divided through by the total agricultural area of each country.

$$T_{mill,i} = B_{bunt,i} \cdot T_{bunt} \cdot (1 - R_{port,stor}) \cdot (1 - R_{stor,mill}) \cdot P_{filt} \cdot P_{fail} \quad \text{(Eq. 17)}$$

The error term $\varepsilon_{mill,i}$ adds variation which results from the individual distribution of the teliospores to the wheat fields, expressed through the asymptotic normal distribution of a binomial experiment.

$$T_{mill,disp,i} = T_{mill,i} \cdot P_{mill,i} + \varepsilon_{mill,i}$$

with additional error. (Eq. 18)

$$\varepsilon_{mill,i} \approx \mathrm{Normal}(0, T_{mill,i} \cdot P_{mill,i} \cdot (1 - P_{mill,i})) \quad \text{(Eq. 19)}$$

The result is rounded to the next full number and truncated below zero.

Table 11: Spillage sub-pathway (Steps 1 to 2: spills during millfeed transport between mills and feedlot storage)

Name of input variable	Symbol	Unit
probability spilled teliospores between mills and feedlot storage dispersed to wheat production area	$P_{feedlot,i}$	[-]
Name of output variable		
spilled teliospores between mills and feedlot storage	$T_{feedlot,i}$	[-]
spilled teliospores between mills and feedlot storage dispersed to wheat production area	$T_{feedlot,disp.i}$	[-]
additional error	ε_i	[-]

Only a part of the teliospores $P_{mill,telio}$ reaches the millfeed. The model does not take the teliospores in the flour into account. But some teliospores $T_{millfeed} \cdot (1-R_{port,stor,i})$ are still present.

$$T_{millfeed,disp,i} = B_{bunt,i} \cdot T_{bunt} \cdot (1 - R_{port,stor}) \cdot (1 - R_{stor,mill}) \cdot (1 - P_{filt} \cdot P_{fail}) + \varepsilon_{millfeed,i} \quad \text{(Eq. 5/6)}$$

The newly, spilled part between the mill and the feed storage is $R_{mill,stor}$ and the probability to reach a wheat production area is $P_{feedlot,i}$. The last probability is estimated by the ratio of area used for wheat production divided through by the total agricultural area of each country.

$$T_{feedlot,i} = T_{millfeed,disp,i} \cdot R_{mill,stor} \quad \text{(Eq. 20)}$$

The error term $\varepsilon_{feedlot,i}$ adds variation which results from the individual distribution of the teliospores to the wheat fields, expressed through the asymptotic normal distribution of a binomial experiment.

$$T_{feedlot,disp,i} = T_{feedlot,i} \cdot P_{feedlot,i} + \varepsilon_{feedlot,i} \quad \text{(Eq. 21)}$$

with additional error

$$\varepsilon_{feedlot,i} \approx \text{Normal}(0, T_{feedlot,i} \cdot P_{feedlot,i} \cdot (1 - P_{feedlot,i})) \quad \text{(Eq. 22)}$$

The result is rounded to the next full number and truncated below zero.

Table 12: Spillage sub-pathway (Steps 1 to 2: spills during millfeed transport between feedlot storage and feedlots)

Name of input variable	Symbol	Unit
probability spilled teliospores between feedlot storage and feedlots dispersed to wheat production area	$P_{feed,i}$	[-]
Name of output variable		
teliospores at feedlots	$T_{feed,i}$	[-]
spilled teliospores between feedlot storage and feedlots dispersed to wheat production area	$T_{feed,disp,i}$	[-]
additional error	ε_i	[-]

At feed storage some teliospores $T_{millfeed,1} \cdot (1-R_{mill,stor,i})$ are still present. The newly, spilled part is $R_{stor,feed}$ and the probability to reach a wheat production area is $P_{feed,i}$. The last probability is estimated by the ratio of area used for wheat production divided through by the total agricultural area of each country.

$$T_{feed,i} = T_{millfeed,disp,i} \cdot (1 - R_{mill,stor}) \cdot R_{stor,feed} \quad \text{(Eq. 23)}$$

The error term $\varepsilon_{feed,i}$ adds variation which results from the individual distribution of the teliospores to the wheat fields, expressed through the asymptotic normal distribution of a binomial experiment.

$$T_{feed,disp,i} \approx T_{feed,i} \cdot P_{feed,i} + \varepsilon_{feed,i} \quad \text{(Eq. 24)}$$

with additional error

$$\varepsilon_{feed,i} = \text{Normal}(0, T_{feed,i} \cdot P_{feed,i} \cdot (1 - P_{feed,i})) \quad \text{(Eq. 25)}$$

The result is rounded to the next full number and truncated below zero.

All spillage is assumed to be homogeneously distributed to the whole country area. This model does not take into account the fact that spillage will occur mostly close to the main routes for transportation, around harbours, storage units and mills. Therefore regional variation in the numbers of spilled teliospores is not reflected in this model.

2.2.2.5. Submodel 5 - Introduction

All teliospores dispersed onto wheat production areas, coming from all pathways between port and feedlot or manures are summed and divided by the total wheat production area $A_{wheat,i}$.

This submodel again does not take into account that spillage will occur mostly close to the main routes for transportation, around harbours, storage units and mills. Therefore again regional variation is not fully reflected in this submodel.

The average number of teliospores per wheat production area is finally multiplied by the proportion of teliospores which are present on the surface of the soil R_{surf}. The resulting variable $T_{intro, surf,i}$ describes the number of teliospores per hectare of wheat production introduced in the first year following use of the US bunted kernel standard. This number is used by the panel as a final model output for further discussion and evaluation. The probabilistic analysis calculates the mean number for all varying or uncertain input variables, the coefficient of variation as a measure of variation and uncertainty, and several percentiles as a description of the resulting distribution. The x % percentile means that in (100-x) % of all combinations the number of teliospores per hectare exceeds the value of the percentile. This might be explained by the variation in time or the uncertainty in the knowledge of correct input values.

Table 13: Introduction sub-pathway (Steps 1 to 11)

Name of input variable	**Symbol**	**Unit**
proportion of wheat production area with suitable temperatures for introduction	R_{intro}	[-]
wheat hectares	$A_{wheat,i}$	[ha]
proportion of wheat production area with suitable temperatures for introduction	R_{intro}	[-]
proportion of teliospores on surface	R_{surf}	[-]
proportion of teliospores surviving annually	R_{surv}	[-]
soil teliospores threshold	$T_{soil,thres}$	[-]
Name of output variable		
total teliospores dispersed to wheat production area	$T_{disp,i}$	[-]
teliospores per wheat hectare with suitable temperatures for introduction on surface	$T_{intro,surf,i}$	[-]
probability calculated for introduction at 1 year	$P_{intro,i}(t = 1y)$	[-]

$$T_{\mathrm{disp},i} = T_{\mathrm{manu,disp},i} + T_{\mathrm{port,disp},i} + T_{\mathrm{stor,disp},i} + T_{\mathrm{mill,disp},i} + T_{\mathrm{feedlot,disp},i} + T_{\mathrm{feed,disp},i} \qquad \text{(Eq. 26)}$$

$$T_{\mathrm{intro,surf},i} = \frac{T_{\mathrm{disp},i} \cdot R_{\mathrm{intro}}}{A_{\mathrm{wheat},i} \cdot R_{\mathrm{intro}}} \cdot R_{\mathrm{surf}} = \frac{T_{\mathrm{disp},i}}{A_{\mathrm{wheat},i}} \cdot R_{\mathrm{surf}} \qquad \text{if } A_{\mathrm{wheat},i} \neq 0 \qquad \text{(Eq. 27)}$$

The result is rounded to the next full number and truncated below zero.

In the USDA APHIS document the number of teliospores per hectare$T_{\mathrm{intro,surf,I}}$ is compared with a assumed threshold $T_{\mathrm{soil,tresh}}$ for bunted kernels to result. Infection is assured when the threshold is exceeded. In case that the threshold is not reached a minimal infection probability is assumed.

$$P_{\mathrm{intro},i}(t = 1y) = \begin{cases} 1, & \text{if } T_{\mathrm{intro,surf},i} \geq T_{\mathrm{soil,thres}} \\ \frac{1}{100\,001}, & \text{if } T_{\mathrm{intro,surf},i} < T_{\mathrm{soil,thres}} \end{cases} \qquad \text{(Eq. 28)}$$

As a result those simulations in which the threshold value is exceeded can be noted. These outcomes reflect again variation and uncertainty in the input parameters, but this calculation is not realized in the @RISK program provided by USDA APHIS.

Assuming that all variation is the result of temporal variation, the number of years until introduction follows a negative binomial distribution with a known average. This approach ignores the fact that the number of teliospores will accumulate over the years.

The USDA APHIS model assumes therefore that the part R_{surv} of the teliospores of the previous year will be still alive in the next year. The probability of infection is calculated for the first five proceeding years after the application of the US bunted kernel standard.

In this approach is assumed that no teliospores from deeper layers of the soil will return to the surface.

Table 14: Introduction sub-pathway (Steps 12 to 15: 2 to 5 years accumulation)

Name of input variable	**Symbol**	**Unit**
proportion of teliospores surviving annually	R_{surv}	[-]
soil teliospores threshold	$T_{\mathrm{soil,thres}}$	[-]
Name of output variable		
probability calculated for introduction at 2 year	$P_{\mathrm{intro},i}(t = 2y)$	[-]
probability calculated for introduction at 3 year	$P_{\mathrm{intro},i}(t = 3y)$	[-]
probability calculated for introduction at n year	$P_{\mathrm{intro},i}(t = n)$	[-]

$$P_{\mathrm{intro},i}(t = 2y) = \begin{cases} 1, & \text{if } T_{\mathrm{intro,surf},i} + T_{\mathrm{intro,surf},i} \cdot R_{\mathrm{surv}} \geq T_{\mathrm{soil,thres}} \\ \frac{1}{100\,001}, & \text{if } T_{\mathrm{intro,surf},i} + T_{\mathrm{intro,surf},i} \cdot R_{\mathrm{surv}} < T_{\mathrm{soil,thres}} \end{cases} \qquad \text{(Eq. 29)}$$

$$P_{\mathrm{intro},i}(t = 3y) = \begin{cases} 1, & \text{if } T_{\mathrm{intro,surf},i} + T_{\mathrm{intro,surf},i} \cdot R_{\mathrm{surv}} + T_{\mathrm{intro,surf},i} \cdot R_{\mathrm{surv}}^{2} \geq T_{\mathrm{soil,thres}} \\ \frac{1}{100\,001}, & \text{if } T_{\mathrm{intro,surf},i} + T_{\mathrm{intro,surf},i} \cdot R_{\mathrm{surv}} + T_{\mathrm{intro,surf},i} \cdot R_{\mathrm{surv}}^{2} < T_{\mathrm{soil,thres}} \end{cases} \qquad \text{(Eq. 30)}$$

$$P_{\mathrm{intro},i}(t = n) = \begin{cases} 1, & \text{if } \sum_{k=0}^{n-1} T_{\mathrm{intro,surf},i} \cdot R_{\mathrm{surv}}^{k} \geq T_{\mathrm{soil,thres}} \\ \frac{1}{100\,001}, & \text{if } \sum_{k=0}^{n-1} T_{\mathrm{intro,surf},i} \cdot R_{\mathrm{surv}}^{k} < T_{\mathrm{soil,thres}} \end{cases} \qquad \text{(Eq. 31)}$$

All results are rounded to the next full number and truncated below zero.

2.2.3. Parameters of the USDA APHIS wheat model

Values and distributions of the parameters used in the five sub-models of the quantitative pathways analysis were evaluated on the basis of the review of the references cited in the document and of the available additional literature and data found by the Panel. The results of this evaluation are presented below.

2.2.3.1. Parameters of the grain export sub-pathway

Bushels/yr of kernels from the affected counties in Arizona, California, Texas ($W_{a,}$ [1/y])

Uniform distributions were used to describe the between-years variability of W_a in the regulated counties of the three states. The use of a uniform distribution is however not justified by any argument and the lower and upper bounds of the distributions were estimated from a limited number of data.

For Arizona and California:

- the lower bounds were set equal to the values recorded in the regulated counties in 2002.
- the upper bounds were set equal to the values recorded in the regulated counties in 1997.

For Texas:

- the lower bound was set equal to a value computed from productions recorded in 2002, 1992 or 1987 depending on the county.
- the upper bound was set equal to a value computed from productions recorded in 1997, 1987 or 2002 depending on the county.

Kg per bushel (U_w, [kg])

This parameter is assumed constant in the USDA APHIS report and set as 27.2 kg/bushel. Referred as test weight, it is a measure of grain density commonly used as grading factor for US wheat, which may be an indicator of milling yield and of the general condition of the grain sample, as problems that occur during the growing season or at harvest often reduce the test weight (U.S. Wheat Associates, online). It shows some variability depending on wheat class, cultivar, year and production site, which is not reflected in the USDA APHIS model.

Positive hectares ($A_{pos,a}$ [ha])

Uniform distributions were used to describe the between-years variability of $A_{pos,a}$ in the regulated counties of the three states. Lower and upper bounds of the distributions were estimated from 10 years of historical data (1997-2006).

The distributions of the historical data used by UDSA APHIS do not look uniform. The standard deviation from uniform distribution is lower than the standard deviations from empirical data (ca. 10 %). The use of uniform distribution for these variables is thus questionable.

Harvested hectares (A_a [ha])

Uniform distributions were used to describe the between years variability of A in Arizona, California and Texas. The use of a uniform distribution is not justified and the lower and upper bounds of the distributions were estimated from a limited number of data. The lower bounds were set equal to the harvested areas in 2002 and the upper bounds were set equal to the harvested areas in 1997. A_a and $A_{pos,a}$ are assumed to be independent in the USDA APHIS model, which can be criticised.

Proportion that are bunted kernels($Q_{bunt,a}$ [-])

A PERT distribution was used to describe the between site-years variability of $Q_{bunt,a}$. The parameters (minimum, most likely and maximum) of the distribution were derived from observed proportions of bunted kernels collected in 348 site-years (Arizona and Texas). The same distribution was used for the three states.

Bunted kernels per kg ($C_{bunt,a}$ [1/kg])

A Pert distribution was used to describe the uncertainty about $C_{bunt,a}$. The parameter values were estimated from personal communications. It is not explained whether the uncertainty described by this distribution represents between-site and year variability, lack of knowledge, or both. This distribution is not consistent with the range of variation shown by Rattan and Auila (1990).

Proportion of bunted kernels escape detection by PPQ ($Q_{nondet,a}$ [-])

Two types of detection were considered:

- high speed optical sorter for Texas,
- manual sampling for California and Arizona.

These two detection techniques correspond to the USDA APHIS standard (Rush et al., 2005; USDA APHIS, 2008).

A Pert distribution was used to describe possible values of $Q_{nondet,a}$ in each type.

For the high speed optical sorter, the parameter values were estimated from published data (Dowell et al., 2002) and the most likely value was set equal to 0.01, assuming a correct use of the optical sorter.

For manual sampling, the parameter values were estimated from personal communications and the most likely value was set equal to 0.33, but the original data were not provided.

Proportion of bunted kernels exported ($Q_{exp,a}$ [-])

The between-years variability of $Q_{exp,a}$ was described using a PERT distribution, with minimum, most likely and maximum values of 0.431, 0.454 and 0.492. These parameters were estimated from ten years of historical data (1997-1998 to 2005--2006, from Vocke and Allen, 2005), as a proportion of total US exported wheat versus total US wheat, as shown in Appendix 42 of the USDA APHIS document (USDA APHIS, 2008).

However, the values used in Appendix 42 for total US wheat do not correspond in Vocke and Allen (2005) to the total US wheat production, but to the total US use of wheat. This is a different parameter which describes the use of the total US wheat supply, i.e., beginning stocks, production and import, and which for 8 out of 10 years had higher values than total US wheat production,

It was assumed that the proportion of wheat exported at the US level was equal to the proportion of wheat exported from the regulated counties.

2.2.3.2. Parameters of the wheat for flour sub-pathway

Probability bunted kernels exported to EU country $P_{part,i}$ [-]

The parameter values were estimated as averages of FAOSTAT statistics from 1995 to 2004, as shown in Appendix 43 of the USDA APHIS document (USDA APHIS, 2008). A Beta distribution was chosen to model the variation, but this distribution does not reflect the temporal variation shown by the data.

Probability exported wheat is a class grown in the US regulated areas $P_{class,i}$ [-]

The model assumes that all wheat imported from regulated areas belong to one of the 3 classes: hard red winter, soft red winter or durum wheat.

The parameters were estimated from USDA FAS 1997-2007 statistics as percentage of the sum of HRW, SRW and Durum wheats vs. all the wheat exported to each EU member state. They choose the

Beta distribution to model the variation but this distribution does not reflect the temporal variation shown by the data.

It is said that USDA-FAS reported no wheat belonging to a class of wheat grown in the US regulated areas was exported to Denmark, Malta or Sweden. Consequently, those countries should not be at risk for *T. indica* introduction. However this does not take into account the possible variability in trade patterns. For example, Denmark imported small quantity of durum wheat from US in 1997 and Sweeden in 1999 and 2000 (Eurostat, online b).

For Austria, the Czech Republic, Estonia, Hungary, Ireland, Latvia, Lithuania and Slovakia a conservative approach was used which considers that all wheat imported belong to the 3 classes grown in regulated areas.

Teliospores per bunted kernel T_{bunt} *[-]*

The number of teliospores per bunted kernels was taken as given by Goates (2008) and Goates pers comm. (2007). These are the highest values cited in these references from intact sori obtained after artificial inoculation. For the data from commercial wheat samples (for which the numbers of teliospores per bunted kernel are lower) the summary does not report whether the sori were intact or not. However the choice of distribution PERT is based only on 4 observations and the choice of a bounded distribution is not appropriate in general.

Rattan and Aujla (1990) reported the spore load in Karnal bunt infected wheat grains of varying disease intensity. In this experiment, spore loads, measured for 30 grains per each grade of infections, varies from 1.13×10^5 for grade 1 (incipient tip infection) to 61.20×10^5 for grade 6 (whole grain converted into spore mass leaving pericarp intact only).

Uncertainty

1. The assumption of a uniform distribution of *T. indica* teliospores considers a total disintegration of the *T. indica* bunted kernels. Total disintegration is unlikely as it is a partial bunt, but it is likely that several sori will be crushed and teliospores will be largely distributed into the grain bulk. No interception of bunted kernels is not a proof of absence because: 1) absence of bunted kernels could be due to pre-export checking and consequent selection of consignments; 2) individual sori in the ventral furrow (groove) of the kernel could be confused by visual examinations with symptoms of other diseases (black point); and 3) no full evidence can be provided that there was no interception of bunted kernels elsewhere.

2. Bechtel et al. (1999) studied the risk of *T. controversa* for China using a pilot mill plant. These authors consider an even distribution of teliospores of *T. controversa* in commercial shipments, however in their experimental design they noticed a high variability in teliospores numbers. In those experimental samples, because of the limited amount of grain handling, sori were not completely broken apart and spores were not evenly dispersed. When a sorus or portion of a sorus was included in a sample that was examined for *T. controversa* spores, the isolation procedure broke up the spore mass and released huge quantities of spores, resulting in large variations in spore counts. The extreme variability also created problems in data analysis. Simple arithmetic averages resulted in standard deviations that were far greater than the means. Therefore, geometric averages were used, and a count range for each replicate was reported.

3. The uncertainty regarding the uniform distribution of teliospores for *Tilletia controversa* due to uncrushed sori or portions of sori may be relevant also for the partial bunt due to *T. indica*, where the sori do not occupy the whole ovary and are frequently observed in the ventral furrow, supposedly more protected from mechanical actions resulting in crushing than the sori of other bunts. This uncertainty on the uniform distribution of teliospores may affect the model output.

Proportion of teliospores spilled from port to storage processing facility ($R_{port,stor}$ [-])

This probability was modelled using a PERT distribution with minimum, most likely and maximum values of 0, 0.0001 and 0.0002, citing as references the grain volume losses between arriving ships and mills reported for truck transport in Latin America (Anderson and Noyes, no date; NAEGA, 2006). Anderson and Noyes (no date) estimated annual costs for storage of hard red winter due to shrinkage and quality loss being around 2 %, but it is not possible to distinguish in this paper between shrinkage and quality loss. NAEGA (2006) is a personal communication from the North American export grain association, reporting observations of an average loss from freight on board to delivered plant mill of 0.001 over 4 years; these ranged from 0.000 (one year) to 0.002 (the 4 years data are not shown and no details are reported on locations and transportation methods). The values of grain losses in this reference are ten-times higher than the PERT distribution values used in the model, so this parameter is underestimated in the USDA APHIS document. Grain spillage estimates at Italian harbours were provided to the Panel by the Italian milling industry association (Italmopa, 2010), indicating 0.003 as an estimate of wheat grain spillage with an efficient unloading operation, 0.004 as a technically acceptable grain spillage/loss, and 0.006 as an estimate of grain spillage/losses with an inefficient unloading operation (Italmopa, 2010). Similarly the European Flour Millers Association provided an estimate of about 0.0025 for outturn loss on ocean transport (European Flour Millers, 2010). These estimates of the Italian and European milling industries are of similar magnitude with respect to the grain losses reported in the personal communication cited in the USDA APHIS document (NAEGA, 2006: where the most likely value was considered as 0.001 and the maximum as 0.002) but considerably higher than the values used in the USDA APHIS document.

It was assumed that:

1. the proportion of teliospore spillage was equal to the proportion of grain spillage

2. the spillage rate for trucks was similar to spillage rates of other transport methods, e.g., rail or barge (but no reference is provided)

3. similar shipping methods (e.g., rail, barge and truck) were used in the European Union and Latin America (Frittelli, 2005; ITTS, 2001; USDOT-FHWA, 2005)

4. Practically, it was also assumed that the spillage rate from port/vessel to storage and from storage to mill was the same

Proportion of teliospores spilled from storage to mill processing facility ($R_{stor,mill}$ [-])

As above.

This probability was modelled using a PERT distribution with minimum, most likely and maximum values of 0, 0.0001 and 0.0002, citing as references the grain volume losses between arriving ships and mills reported for truck transport in Latin America (Anderson and Noyes, no date; NAEGA, 2006). Also for this parameter, as for $R_{port,stor}$, the PERT distribution values used in the model are ten-times lower than the grain loss estimates in NAEGA (2006). Hence, $R_{stor,mill}$ is underestimated in the USDA APHIS document with respect to the reference cited.

Wheat grain spillage for Italy from storage to mill (Italmopa, 2010) was estimated respectively as 0.0006 and 0.001 with efficient and inefficient transportation systems. The European Flour Millers association (2010) provided an estimate of about 0.0025 for transit losses after boat unloading.

Assumptions were that:

1. the proportion of teliospores spillage was equal to the proportion of grain spillage

2. the spillage rate for trucks was similar to the spillage rates of other transport methods, e.g., rail or barge

3. similar shipping methods (e.g., rail, barge and truck) were used in the European Union and Latin America (Frittelli, 2005; ITTS, 2001; USDOT-FHWA, 2005)

4. Practically it was assumed that the spillage rate from port/vessel to storage and from storage to mill was the same

Probability teliospores enter house filter P_{filt} [-]

This probability was modelled using a Beta distribution where s = number of teliospores present in the house filter (209,664) and n = the total number of teliospores present in the grain prior to milling (11,207,945). Data were obtained from research using a pilot commercial flour mill at Kansas State University and standard milling procedures (Bechtel et al., 1999).

However there is very high uncertainty on this parameter. The mill used was a pilot scale commercial mill from Kansas State University, where the house filter was a cloth-filter dust control system. According to the authors (Bechtel et al., 1999), the cleaning house filter contained large numbers of filter socks from which only a small fraction of the dust could be removed; these socks may have held large numbers of spores that could not be quantified. The values used in the Beta distribution come from only one replicate. In the second replicate, 1,966,745 spores were reported in the initial mixture of grain contaminated with *T. controversa* and 1,055,520 in the house filter, although high variability was reported probably due to the presence of intact sori broken during the process. In this second replicate 3,962,431 spores were counted in the cleanings and mill feed (201.5 % of the spores count in the initial mixture vs. 21.1 % of the first replicate). This second replicate has not been considered in this study. In the risk assessment for the importation of *T. controversa* into China (Martinez et al., 1998), which is also cited as reference for this parameter, only the values from the first replicate of the study later published by Bechtel et al. are considered.

Assumptions

1. EU grain mills would be technically similar to US mills, particularly to the pilot scale commercial mills from Kansas University used in the study by Bechtel et al. (1999).
2. *T. indica* and *T. controversa* teliospores would distribute similarly during the milling process.

Probability house filter fails P_{fail} [-]

This probability was modelled using a PERT distribution with minimum, most likely and maximum values of 0.000, 0.040 and 0.090, citing, as a reference for the most likely value of 0.040, the risk assessment by Martinez et al. (1998) and a personal communication by Peterson (2006). Martinez et al. (1998) considered a filter efficiency of 96 % and therefore estimated that 4 % of 1.8 % of the teliospores entering the filter may escape. According to Peterson (2006), the value of 4 % comes from the filter manufacturers specifications and the *T. controversa* teliospores size range. Martinez et al. (1998) also estimated that, because occasionally filters are damaged or temporally removed, up to 10 % of the spores could escape the mill filter system annually. The value of 0.000 as minimum in the USDA APHIS document does not seem justified by the cited references. It is also not clear why as a maximum value of 0.090 was used rather than the estimate of 0.100 according to Martinez et al. (1998).

Probability teliospores in millfeed $P_{telio,mill}$ [-]

This probability was also modelled using a Beta distribution, where s = number of teliospores present in millfeed and cleanings (2,368,792) and n = the total number of teliospores present in the grain prior to milling (11,207,945). Data were obtained from the same research as for P_{filt} (Bechtel et al., 1999), using, as with the previous parameter, only data from first replicate.

In the second replicate, 1,966,745 spores were reported in the initial mixture of grain contaminated with *T. controversa* and 3,962,431 spores were counted in the cleanings and mill feed (201.5 % of the spores count in the initial mixture vs. 21.1 % of the first replicate).

Using a Beta distribution they are assuming this value is almost a constant, this does not reflect the uncertainty.

2.2.3.3. Parameters of the Millfeed Products Sub-Pathway

Proportion of teliospores spilled from mill to feedlot storage Rmill,stor [-]

Uniform distribution from minimum 0.001 to maximum 0.01 based on industry estimates for millfeed distribution losses in China (US Wheat Associates Beijing/SAGR, no date, cited in USDA APHIS, 2008). The data (n = 19) are presented in Appendix 5 of the USDA APHIS document with a range from 0.001 to 0.005. The data which seem to refer to the transport from mill to feedlot storage (with destination feed factory, n = 6) vary from 0.001 to 0.003.

Proportion of teliospores spilled from feedlot storage to feedlots Rstor,feed [-]

A uniform distribution ranging from minimum 0.001 to maximum 0.01 was based on industry estimates for millfeed distribution losses in China (US Wheat Associates Beijing/SAGR, no date, cited in USDA APHIS, 2008).

The data (n = 19) from US Wheat Associates Beijing (no date) are presented in Appendix 5 of the USDA APHIS document with a range from 0.001 to 0.005, The data which seem to specifically refer to the transport from mill to feedlots (with destination “breeding”, n = 2) vary from 0.0025 to 0.003.

Proportion teliospores that survive cattle digestion R_{digest} *[-]*

This probability was modelled using a PERT distribution with minimum, most likely and maximum values of 0.075, 0.172 and 0.269, using as the most likely value the approximate mean germination proportion of 0.172 for *T. caries* teliospores after cattle digestion (Smilanick et al., 1986).The minimum and maximum teliospores germination values were estimated by assuming a normal distribution and using Z-values to calculate the 99 % confidence interval around 0.172 (Appendix 51 and 52 of the USDA APHIS document).

Smilanick et al. (1986) studied teliospores germination of *T. indica*, *T. caries* and *T. controversa* after digestion by female leghorn chicken (n=4) and grasshoppers. Results for *T. indica* are expressed in histograms representing average and standard deviation of % germination, but data are not shown. Digestion of teliospores after placing in the rumen of a Holstein cow was studied only for *T. caries* and *T. controversa*, due to quarantine restrictions.

Probability manure dispersed to wheat production area $P_{manu,i}$ *[-]*

This probability was modelled for each country using a Beta distribution where s = average number of harvested wheat hectares between 1996 and 2005 and n = the average hectares of agricultural land between 1994 and 2003 (FAOSTAT 2006, 2007; Appendix 55 and 56 of the USDA APHIS document). Crop rotation and therefore the fact that wheat may be grown each year on different fields is not considered in the model.

Probability feed lot manure used as fertilizer P_{fert} *[-]*

This probability was modelled using a PERT distribution with minimum, most likely and maximum values of 0.155, 0.270 and 0.385, using as most likely value the percentage of Texas farmers using feedlot manure as fertilizer (0.270) in a 1991 TCFA/TAEX survey (Sweeten, 1991). The minimum and maximum values were estimated by assuming a normal distribution and using Z-values to calculate 99 % confidence interval around 0.270 (Appendix 53 and 54). The 1991 TCFA/TAEX survey shows that the farmers use of feedlot manure as fertilizer has decreased from 0.52 to 0.27, but also that this depends on the distance from the feed yard, with a percentage of 0.57 for farmers distant 10 or less miles, 0.24 for distance of 10-20 miles and 0.19 for distance of 20 or more miles.

The overall assumption in using values from the 1991 TCFA/TAEX survey for estimation of P_{fert} is that the probability of manure being used as fertilizer in the EU is similar to the Texas feedlot manure use in 1991. Although recent EUROSTAT statistical surveys are not available at EU level on this parameter, the manure utilisation on agriculture land in EU countries is generally estimated to be higher than the 1991 TCFA/TAEX survey. Menzi (2002) reported estimates for 20 EU countries on manure application to arable crops and grassland, which was on average above 90 % for all manure categories (slurry/liquid manure; solid manure cattle pigs; poultry manure).

2.2.3.4. Parameters of the spillage sub-pathway

The spillage sub-pathway in the USDA APHIS model does not consider crop rotation. Wheat may be grown each year on different fields and therefore, considering the long survival of the *T. indica* teliospores in the soil (see Section 1.2 of this opinion), spilled teliospores may land this year on a field on which wheat is not grown but will be in future years.

In the spillage sub-pathway it is generally assumed that teliospores on spilled grain are evenly distributed over the whole wheat production area of each EU importing country. However, the possible role of birds or insects in the distribution of teliospores to wheat sown fields is not considered. A paper by Castro Duarte et al. (2005) studied the survival of *T. indica* teliospores ingested by birds (freely wandering birds, such as sparrows, pigeons, ravens). It concluded that the difference between average germination of grain ingested/non ingested by birds was 16.3 % for sparrows, 79.2 % for doves, 76.1 % for pigeons, 77.3 % for small pigeons and 93.9 % for ravens. Also insects may contribute to dispersion: after digestion by grasshoppers (Smilanick et al., 1986) a high teliospores germination rate was observed (more than 75 % for *T. controversa*, more than 25 % for *T. indica* and *T. caries*).

Probability spilled teliospores from port to grain storage dispersed to wheat production area $P_{port,i}$ *[-]*

The same probability was used for $P_{port,i}$, $P_{stor,i}$., $P_{mill,I}$, $P_{feedlot,I}$ and $P_{feed,i}$. This probability was modelled for each country using a Beta distribution where s = average number of harvested wheat hectares between 1996 and 2005 and n = the total country area (CIA 2006; FAOSTAT 2006, 2007; Appendix 55 of the USDA APHIS document). It was assumed that the grain transportation corridors (roads, railways) have an equal probability of occurring in wheat production and non-wheat production area.

Probability spilled teliospores from grain storage to mill dispersed to wheat production area $P_{stor,i}$ *[-]*

The same probability was used for $P_{port,i}$, $P_{stor,i}$., $P_{mill,I}$, $P_{feedlot,I}$ and $P_{feed,}$. It was modelled for each country using a Beta distribution where *s* = average number of harvested wheat hectares between 1996 and 2005 and *n* = the total country area (CIA 2006; FAOSTAT 2006, 2007; Appendix 55 of the USDA APHIS document). Also for this parameter, it was assumed that the grain transportation corridors (roads, railways) have an equal probability of occurring in wheat production and non-wheat production area.

Probability teliospores released during milling dispersed to wheat production area $P_{mill,i}$ *[-]*

The same probability was used for $P_{port,i}$, $P_{stor,i}$.,$P_{mill,I}$, $P_{feedlot,I}$ and $P_{feed,i}$. It was modelled for each country using a Beta distribution where s = average number of harvested wheat hectares between 1996 and 2005 and n = the total country area (CIA 2006; FAOSTAT 2006, 2007; Appendix 55 of the USDA APHIS document).

For the teliospores escaping the mill filtration systems, it is assumed that air borne teliospores would have an equal likelihood of being deposited in wheat production and non-wheat production areas, based on the fact that teliospores can be transported long distances via wind.

Probability spilled teliospores from mill to feedlot storage dispersed to wheat production area *(*$P_{feedlot,i}$ *[-])*

The same probability was used for $P_{port,i}$, $P_{stor,i}$.,$P_{mill,I}$, $P_{feedlot,I}$ and $P_{feed,i}$. It was modelled for each country using a Beta distribution where *s* = average number of harvested wheat hectares between 1996 and 2005 and *n* = the total country area (data, from the CIA World fact book 2006 and from FAOSTAT statistics 2006 and 2007, presented in Appendix 55 of the USDA APHIS document).

Probability spilled teliospores from feedlot storage to feedlot dispersed to wheat production area *(*$P_{feed,i}$ *[-])*

The same probability was used for $P_{port,i}$, $P_{stor,i}$.,$P_{mill,I}$, $P_{feedlot,I}$ and $P_{feed,i}$. It was modelled for each country using a Beta distribution where *s* = average number of harvested wheat hectares between 1996 and 2005 and *n* = the total country area (data, as above, from the CIA World fact book 2006 and from FAOSTAT statistics 2006 and 2007, presented in Appendix 55 of the USDA APHIS document).

2.2.3.5. Parameters of the introduction sub-pathway

Proportion of wheat production area with suitable temperatures for introduction R_{intro} *[-]*

This parameter was studied by the EU project with results different for countries and years. However, in this model this parameter is superfluous as it cancels itself out (they assume uniform distribution of teliospores everywhere).

An EU funded research project entitled "Karnal bunt risks" (Sansford et al., 2006) studied the establishment potential of *T. indica* in the EU territory by an approach combining a pathogen model with crop phenology models. Murray (2004) reviewed pathogen models that could be used to predict establishment of *T. indica* and found the Humid Thermal Index (HTI) model of Jhorar et al. (1992) to be the most suitable for this purpose. The HTI model was combined with crop phenology models for bread wheat (*T. aestivum*) (Porter, 1984) and durum wheat (*T. durum*) (Miglietta, 1989). The combined modelling approach was deployed to identify if overlap occurs between the susceptible phenological stage of wheat and the meteorological conditions, within the range predicted by the HTI, to be suitable for *T. indica* infection and disease development.

The results from the study was that there is a substantial risk of infection by *T. indica* in most years in the EU for both durum and bread wheat. The risk is not greatly influenced by the management of the crops in terms of sowing date or maturity class. Elevation also does not have a great influence on the risk. However, climatic variation at the continental European scale is a strong determinant of the risk of establishment of *T. indica*. Risk is lower further north and further west in Europe. Northern regions may on occasion be too cold and western regions too moist to favour infection and disease development. However, on a year by year basis using historic meteorological data, there are always years and locations in Europe which have been shown to be favourable to infection and disease development.

The overall conclusions of the EU-funded project were:

- There is a substantial risk of infection of bread and durum wheat by *T. indica* and development of Karnal bunt in most years in the EU

- The risk is not greatly linked to management of the crops in terms of sowing date or choice of varieties based upon their phenology (maturity class)

- Climatic variation at the continental European scale is a strong determinant of the risk of establishment of *T. indica*

- The timing of germination of *T. indica* teliospores in Europe in relation to the period at which European bread and durum wheat varieties are susceptible to infection falls within the window of crop phenology and climate examined

- Uncertainty exists in the maximum length of teliospore survival and its implications

Wheat hectares $A_{wheat,i}$ *[ha]*

This parameter was modelled using a PERT distribution with minimum, mean and maximum harvested wheat hectares for each country from 1996 to 2005 (data, from FAOSTAT statistics 2006 and 2007, presented in Appendix 55 of the USDA APHIS document) set as minimum, most likely and maximum values. It has to be noted that for the harvested wheat hectares in US they used a uniform distribution.

Proportion of teliospores on surface R_{surf} [-]

The proportion of teliospores on the soil surface was modelled using a uniform distribution from minimum 10 % to maximum 100 %, according to estimates made by Garrett and Bowden (2002), based on conversations with Karnal bunt researchers. There is uncertainty as these estimates are based only on personal communications.

Proportion of teliospores surviving annually R_{surv} [-]

The proportion of teliospores surviving annually is modelled using a PERT distribution with 0.3, 0.55 and 0.80 respectively as minimum, most likely and maximum values, based on estimates made by Garrett and Bowden (2002) after conversations with Karnal bunt experts (range from 0.3 to 0.8 depending on teliospore age, weather variables influencing overwintering, cultural practices such as irrigation, position in the soil profile). There is uncertainty as these estimates are based on personal communications. Cohort specific survival rate is not considered and the same survival rate is used for each year without considering changes in teliospore germinability and mortality.

Soil teliospores threshold $T_{soil,thres}$ [-]

The soil surface teliospore threshold for *T. indica* introduction is considered constant as 150,000 teliospores/ha, citing as reference the teliospore threshold of 15/m^2 of Murray and Sansford (2005). However, this is a misinterpretation of Murray and Sansford (2005), who did not give any value as a threshold, but showed the relationship between number of bunted kernels and teliospores, following Garrett and Bowden (2002).

According to Rush et al. (2005), the relationship between inoculum density and disease incidence has yet to be elucidated for Karnal bunt. Also quoted, from a personal communication from G. Peterson, was that studies in Arizona that attempted to determine the minimum teliospore threshold required for infection have been unsuccessful to date because of the lack of suitable environmental conditions, even in the presence of a misting system. Also Murray and Brennan (1998) found no report of a minimum threshold number of teliospores required for infection. There is therefore very high uncertainty regarding this parameter and indeed whether it exists.

The data provided enable to predict the number of bunted kernels in the EU countries based on the number of teliospores, without considering a threshold (Murray and Sansford, 2005)

Proportion of teliospores surviving annually R_{surv} [-]

(Steps 12 to 15: 2 to 5 years accumulation). See above.

Soil teliospores threshold $T_{soil,thres}$ [-]

(Steps 12 to 15: 2 to 5 years accumulation). See above.

2.2.4. Parameters of the USDA APHIS desert durum wheat model

For the desert durum wheat model, generally the same set of distributions and parameters of the wheat for grain model, as listed above, were used. Only three parameters were specifically set for the desert durum wheat model: W_a, $P_{part,i}$ and $P_{class,i}$:.

Bushels/yr of kernels from the affected counties in Arizona, California, Texas ($W_{a,}$ [1/y])

Uniform distributions were used to describe the between-years variability of W_a in the regulated counties of Arizona and California, setting the lower upper bounds of the distributions as follows:

- the lower bounds were set equal to the values recorded in the regulated counties in 2002.
- the upper bounds were set equal to the values recorded in the regulated counties in 1997.

For Arizona, data for durum wheat harvested bushels were not available for La Paz county in 1997 and for Pinal county in 2002. Therefore, it was assumed that the whole wheat production of these counties was durum wheat.

For California, to calculate durum wheat harvested bushels for Imperial county in 1997 and 2002, an average production was used.

Probability bunted kernels exported to Italy $P_{part,i}$ *[-]*

The percentages of durum wheat exported to Italy in the years from 1998 to 2005 were calculated from data from FGIS and US Wheat Associates (appendix 46 USDA APHIS). A Beta distribution was chosen to model the variation, but this distribution does not reflect the temporal variation shown by the data.

Probability exported wheat is a class grown in the US regulated areas $P_{class,i}$ *[-]*

For desert durum the parameter $P_{class,}$ was estimated from FGIS (no date) from data presented in Appendix 47 of the USDA APHIS document.The percentages of desert durum wheat in relation to total wheat export to Italy in the years from 1997 to 2006 were calculated. A Beta distribution was chosen to model the variation, but this distribution does not reflect the temporal variation shown by the data.

2.2.5. Model outputs obtained with the USDA APHIS model

USDA APHIS supplied the EFSA Panel with their implementation of the model in @RISK software. To obtain intermediate results, like the average number of teliospores per hectare in each EU country, the code was rerun by the EFSA Panel. The following adjustments were included:

- all intermediate results were used with full precision and not rounded to the next integer.
- the additional error terms of the model were separated to enable @RISK to perform a sensitivity analysis on all input variables
- the introduction pathway was ended by the “Average number of teliospores on the surface of wheat production area one year after implementation” for each EU country.

These adjustments did not affect the original model scenario, structure or parametrisation.

The results for desert durum wheat were obtained with the implementation for wheat by exchanging the specific parameters for desert durum wheat and restricting the simulation to Italy. The implementation for desert durum wheat provided by USDA APHIS was not used due to inconsistency in one cell of the EXCEL program (for details see EFSA, 2010).

2.2.5.1. Discussion of the model outputs

Wheat for grain

10,000 Monte Carlo simulations were performed with the USDA APHIS model and numbers of teliospores were computed per ha for each country. The probability distributions of number of teliospores per ha are described in Table 15 for wheat for grain. The results shows that the mean number of teliospores per ha one year after import ranged from 2 10^{-4} (Sweden) to 841.66 (Cyprus). The mean number of teliospores per ha is higher than 150 for Belgium-Luxembourg (164), Estonia (216.2), Italy (151.2), and The Netherlands (238.3). The uncertainty is high as shown by the coefficients of variation derived from the simulations which ranged from 136 % to 200 %. Due to this high uncertainty, the differences between low and high quantiles are important. Thus, Table 15 shows that there is more than a 5 % chance to get less than 15 teliospores per ha in all countries but Cyprus and that there is more than a 5 % chance to get more than 150 teliospores per ha in Belgium-Luxembourg, Bulgaria, Cyprus, Estonia, Italy, Netherlands, Romania, and Slovenia. There is a 1 % chance to get more than 1500 teliospores per ha in Cyprus, Estonia, and The Netherlands.

Table 15 does not reflect the possible within-country spatial heterogeneity of the number of teliospores per ha. Thus, for a given country, the number of teliospores per ha can be higher or lower than the values reported in this Table depending on the spatial distribution of teliospores within the country.

The spatial distribution is not considered in the model although this spatial distribution can lead to densities of teliospores very different from the mean values. For illustration, if we assume the density of teliospores randomly distributed according to a Poisson probability distribution, there is a 1 % chance to get more than 19 teliospores per ha and to get les than 4 bunted kernels per ha in Poland if the average number of bunted kernels per ha is 10.65 in this country. More extreme densities could be reached in case of spatial aggregation of the number of teliospores per ha.

Table 15: Probability distributions of number of teliospores per ha for each EU country for the wheat for grain model

Teliospores on surface after 1st year per member state [1/(ha y)] / Simulation with the original wheat for grain model for EU countries

State	Mean	CV	1 %	5 %	50 %	95 %	99 %
Austria	0.660	136%	0.0101	0.0287	0.338	2.41	4.39
Belgium-Luxembourg	167	136%	2.7108	7.44	86.6	614	1117
Bulgaria	62.0	137%	1.0116	2.74	31.9	226	420
Cyprus	842	138%	13.1480	36.7	425	3073	5546
Czech Republic	0.265	136%	4.07E-03	0.0116	0.136	0.973	1.73
Denmark	1.82E-03	200%	5.03E-06	2.70E-05	6.27E-04	7.44E-03	0.0170
Estonia	223	140%	3.4311	9.80	114	818	1514
Finland	0.833	139%	0.0121	0.0355	0.419	3.08	5.67
France	0.593	136%	9.53E-03	0.0266	0.305	2.18	3.93
Germany	7.00	136%	0.1132	0.308	3.60	25.6	47.0
Greece	0.866	136%	0.0136	0.0392	0.449	3.15	5.81
Hungary	0.607	137%	9.11E-03	0.0263	0.310	2.21	3.95
Ireland	6.06	136%	0.0980	0.268	3.10	22.2	39.2
Italy	154	136%	2.5586	6.88	79.5	565	1036
Latvia	37.3	137%	0.5969	1.68	19.2	136	250
Lithuania	9.15	136%	0.1504	0.4081	4.74	33.6	61.0
Malta	0.122	198%	5.18E-04	2.58E-03	0.0504	0.469	1.03
Netherlands	243	137%	3.8616	10.8	125	894	1606
Poland	10.6	136%	0.1694	0.474	5.47	39.1	71.2
Portugal	1.80	138%	0.0281	0.0791	0.915	6.61	11.9
Romania	80.8	137%	1.2818	3.60	41.6	295	533
Slovakia	0.0274	142%	2.66E-04	9.98E-04	0.0139	0.102	0.186
Slovenia	49.1	137%	0.7986	2.15	25.1	179	332
Spain	23.2	136%	0.3713	1.03	11.9	85.1	151
Sweden	2.27E-04	170%	1.02E-06	4.81E-06	9.77E-05	8.88E-04	1.77E-03
United Kingdom	0.422	136%	6.97E-03	0.0192	0.219	1.54	2.79

Durum wheat

For the desert durum wheat pathway, the model was set starting from the wheat model and updating the three parameters specific for desert durum with values and distributions described in Section 2.2.4. 10,000 Monte Carlo simulations were performed with the USDA APHIS desert durum wheat model and numbers of teliospores were computed per ha for Italy. The probability distributions of number of teliospores per ha are described in Table 16 for the desert durum wheat pathway for Italy. The mean number of teliospores per ha one year after import was equal to 3094.4 per ha. The uncertainty is high as shown by the coefficient of variation derived from the simulations which was equal to 138 %. Due to this high uncertainty, the differences between low and high quantiles are important: there is a 5% chance to get less than 116.19 teliospores per ha, but a 5 % chance to get more than 11461.45 teliospores per ha. There is a 1 % chance to get more than 20116.56 teliospores per ha. As noted in the case for wheat for grain, these values does not reflect a possible within country spatial heterogeneity of the number of teliospores per ha.

Table 16: Probability distributions of number of teliospores per ha for each EU country for the desert durum wheat for grain model

Teliospores on surface after 1st year [1/(ha y)] / Simulation with original desert durum model for Italy

Mean	CV	1 %	5 %	50 %	95 %	99 %
3094	138%	34.2	116	1538	11461	20117

2.2.5.2. Sensitivity analysis on the output

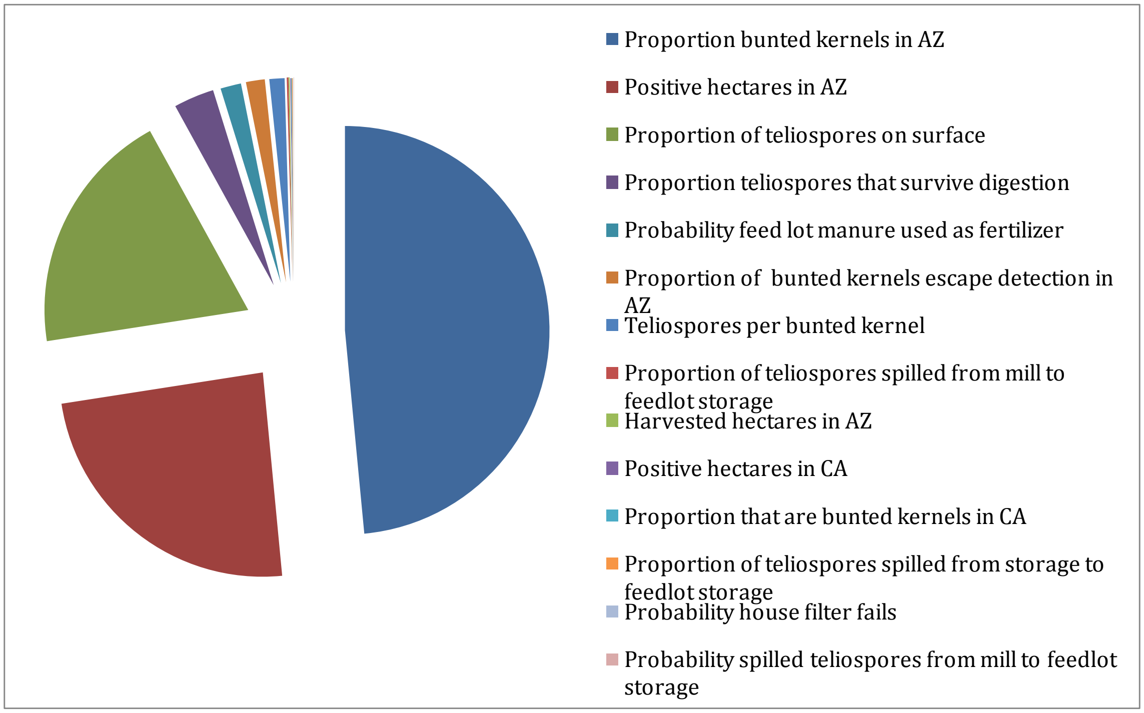
Wheat for grain

Table 17 shows the sensitivity indices derived from the 10,000 Monte Carlo simulations performed with the USDA APHIS model for wheat for grain. These indices indicate the influence of each parameter on the total number of teliospores in EU per year. Seven parameters have indices higher than 0.05: proportion of kernels that are bunted in regulated counties of Arizona (index=0.565), positive ha in Arizona (index=0.398), proportion of teliospores on surface (index=0.358), proportion of teliospores that survive cattle digestion (index=0.145), probability feed lot manure used as fertilizer (index=0.104), proportion of bunted kernels escaping detection by PPQ in Arizona (index=0.099), teliospores per bunted kernel (index=0.089). These results show that, among the most influential parameters, three are related to the wheat production and *T. indica* detection in Arizona.

Table 17: Sensitivity indices, derived from the 10,000 Monte Carlo simulations performed with the original USDA APHIS model for wheat for grain, on average teliospores on surface after 1st year

Name	State	Sensitivity
Proportion that are bunted kernels	Arizona	0.565
Positive hectares	Arizona	0.398
Proportion of teliospores on surface	Total US	0.358
Proportion teliospores that survive cattle digestion	Total US	0.145
Probability feed lot manure used as fertilizer	Total US	0.104
Proportion of bunted kernels escape detection by PPQ	Arizona	0.099
Teliospores per bunted kernel	Total US	0.089
Proportion of teliospores spilled from mill to feedlot storage	Total US	0.029
Harvested hectares	Arizona	-0.024
Positive hectares	California	0.02
Proportion that are bunted kernels	California	0.02
Proportion of teliospores spilled from storage to feedlot storage	Total US	0.02
Probability house filter fails	Total US	0.012
Probability spilled teliospores from mill to feedlot storage dispersed to wheat production areas	Finland	0.011
Probability spilled teliospores from port to grain storage dispersed to wheat production areas	France	-0.011

Standardized Regression Coefficients (b), R²=0.673
Variables with b>=0.01 included



Legend: Plotted are the proportions of the squared sensitivity indices to the total R^2 value, which can be interpreted as importance of the influence factor on the overall variation / uncertainty.

Figure 3: Importance of the influence variable in the original USDA APHIS model for wheat for grain, on average teliospores on surface after 1st year

Desert durum wheat

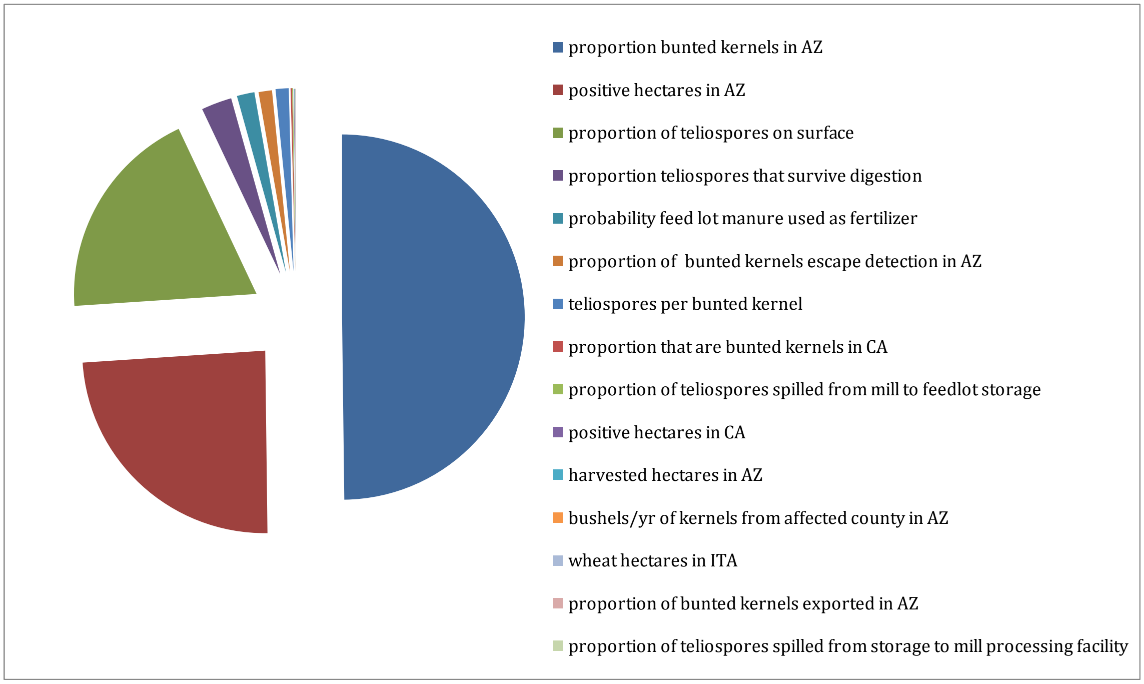
Table 18 shows the sensitivity indices derived from the 10,000 Monte Carlo simulations performed with the USDA APHIS model for desert durum wheat. These indices indicate the influence of each parameter on the number of teliospores on the soil surface in Italy. The indices reported in Table 18 for durum wheat are similar to those shown in Table 17 for wheat for grain; the indices are higher than 0.05 for the same seven parameters: proportion of kernels that are bunted in regulated counties of Arizona (index=0.576), positive ha in Arizona (index=0.401), proportion of teliospores on surface (index=0.356), proportion of teliospores that survive cattle digestion (index=0.134), probability feed lot manure used as fertilizer (index=0.102), proportion of bunted kernels escaping detection by PPQ in Arizona (index=0.089), teliospores per bunted kernel (index=0.088).

Table 18: Sensitivity indices, derived from the 10,000 Monte Carlo simulations performed with the original USDA APHIS model for desert durum for grain, on average teliospores on surface after 1st year

Name	State	Sensitivity
proportion that are bunted kernels	Arizona	0.576
positive hectares	Arizona	0.401
proportion of teliospores on surface	Total US	0.356
proportion teliospores that survive cattle digestion	Total US	0.134
probability feed lot manure used as fertilizer	Total US	0.102

proportion of bunted kernels escape detection by PPQ	Arizona	0.089
teliospores per bunted kernel	Total US	0.088
proportion that are bunted kernels	California	0.031
proportion of teliospores spilled from mill to feedlot storage	Total US	0.023
positive hectares	California	0.019
harvested hectares	Arizona	-0.015
bushels/yr of kernels from affected county	Arizona	0.014
Error to spilled teliospores from port to grain storage dispersed to wheat production areas	Italy	-0.014
wheat hectares	Italy	-0.014
proportion of bunted kernels exported	Arizona	0.013
proportion of teliospores spilled from storage to mill processing facility	Total US	0.012
Error to spilled teliospores from grain storage to mill dispersed to wheat production areas	Italy	0.011

Standardized Regression Coefficients (b), R²=0.666
Variables with b>=0.01 included



Legend: Plotted are the proportions of the squared sensitivity indices to the total R^2 value, which can be interpreted as importance of the influence factor on the overall variation / uncertainty.

Figure 4: Importance of the influence variable in the original USDA APHIS model for desert durum for grain, on average teliospores on surface after 1st year

2.2.6. Definition of parameters values and distributions for updated wheat and desert durum model

2.2.6.1. New probability distributions for parameters of the US wheat for grain model

Following the review of the parameters values and distributions (see Section 2.2.2.), new probability distributions have been set to alternative distributions of some parameters to be used in an updated simulation model for the wheat for grain pathway.

The parameters which present changes in their set of values and/or in their distribution, with respect to the original US models, are discussed below. For all the other parameters, the set of values and the distributions remain unchanged.

Parameters of the grain export sub-pathway

Bushels/yr of kernels from the affected counties in Arizona, California, Texas (Wa, [1/y])

For this parameter, the available production data in bushels/year of all wheat types from individual regulated counties of Arizona, California and Texas were extracted from the Quick Stats webpage of the USDA National Agricultural Statistics Service (USDA NASS, online) for the period 1997-2008. For Arizona, the dataset included the production of Lapaz, Maricopa, Pinal and Yuma counties for the years 1997-2004 and 2008; for the year 2002, missing data for Lapaz, Maricopa and Pinal counties were obtained from the appendix 32 of the USDA APHIS document. For Califonia, the dataset included the production of Imperial and Riverside counties for all the years 1997-2007. For Texas, the dataset included the production of individual regulated counties (Archer, Baylor, El Paso, Hudspeth, Knox, McCulloch, Mills, San Saba, Throckmorton and Young) for most of the years 1997-2008; the production of the missing years for the El Paso, Hudspeth and Mills counties were estimated by the county mean values for the available years of the period 1997-2008.

Lognormal distributions were fitted to the yearly production per State (for each State the sum of production of the considered regulated counties) by Maximum Likelihood estimation. All estimated distributions shown larger variation as in the original model of US Aphis.

Bushels per year of wheat kernels from the affected counties in Arizona, California, Texas

Symbol:	**W_a**	Unit:	[bushels / y]								
Wheat model		Distribution	Para 1	Para 2	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Arizona	original	UNIFORM (min, max)	8670164	8906645	8788405	0.78%	8672529	8681988	8788405	8894821	8904280
	updated	LOGNORMAL (mean, std dev)	9940593	2364622	9940593	23.79%	5603112	6574557	9670750	14225049	16691333
California	original	UNIFORM (min, max)	5321969	8783878	7052924	14.17%	5356588	5495064	7052924	8610783	8749259
	updated	LOGNORMAL (mean, std dev)	6121506	2298648	6121506	37.55%	2461931	3153328	5730796	10415033	13339943
Texas	original	UNIFORM (min, max)	5045279	10203714	7624497	19.53%	5096863	5303201	7624497	9945792	10152130
	updated	LOGNORMAL (mean, std dev)	7856670	3356229	7856670	42.72%	2787431	3684489	7225049	14167860	18727399

Para = parameter; perc. = percentile.

Kg per bushel (U_w, [kg])

To explore the variation of test weight for wheat produced in the regulated counties, test weights (expressed in lb/bu) of desert durum wheat, hard red wheat and hard white wheat varieties were obtained from California crop quality reports for the years 2005-2009 (California Wheat Commission, 2005a and b, 2006a and b, 2007a and b, 2008a and b, 2009a and b) and converted in kg/bu.

A Lognormal distribution was selected as the best fitting distribution to represent the empirical test data. Also fitted were Lognormal-, Gamma- and Weibull-distributions using the Maximum-Likelihood principle. The selection was done by minimizing the Andersen-Darling distance between fitted distributions and empirical data.

kg per bushel wheat

Symbol:	**U_w**	Unit:	[kg / bushel]								
Wheat model		Distribution	Para 1	Para 2	mean	CV	1%-perc.	5% -perc.	median	95%-erc.	99%-perc.
Total	original	COSTANT(value)	27.22		27.22	0.00%	27.22	27.22	27.22	27.22	27.22
	updated	LOGNORMAL (mean, std dev)	28.36	0.59	28.36	2.08%	27.02	27.41	28.36	29.34	29.76

Para = parameter; perc. = percentile.

Positive hectares ($A_{pos,a}$ [ha])

The uniform distribution used for this parameter in the USDA APHIS document does not seem to reflect the variability appropriate between-years variability of $A_{pos,a}$ in the regulated counties of the three states. Therefore, lognormals distributions were fitted to the empirical data. The distributions show larger variation and some differences in the mean values.

Positive hectares

Symbol:	**A_pos_a**	Unit:	[ha]								
Wheat model		Distribution	Para 1	Para 2	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Arizona	original	UNIFORM (min, max)	0.00	1650.63	825.32	57.74%	16.51	82.53	825.32	1568.10	1634.12
	updated	LOGNORMAL (mean, std dev)	553.72	586.69	553.72	105.96%	50.50	91.22	380.06	1583.41	2860.00
California	original	UNIFORM (min, max)	0.00	105.30	52.65	57.74%	1.05	5.27	52.65	100.04	104.25
	updated	LOGNORMAL (mean, std dev)	31.84	43.426	31.84	136.38%	1.73	3.49	18.83	101.64	204.40
Texas	original	UNIFORM (min, max)	0.00	2147.31	1073.66	57.74%	21.47	107.37	1073.66	2039.94	2125.84
	updated	LOGNORMAL (mean, std dev)	284.270	671.372	284.27	236.17%	4.55	11.59	110.84	1059.55	2699.82

Para = parameter; perc. = percentile.

Harvested hectares (A_a [ha])

For this parameter, the data on harvested hectares of all wheat types in acres/year from individual regulated counties of Arizona, California and Texas were extracted from the Quick Stats webpage of the USDA National Agricultural Statistics Service (USDA NASS, online) for the period 1997-2008 and converted into hectares/year. For Arizona, the dataset included the harvested hectares of Lapaz, Maricopa, Pinal and Yuma counties for the years 1997-2004 and 2008; for the year 2002, the missing data for Lapaz, Maricopa and Pinal counties were obtained from the appendix 32 of the USDA APHIS document. For California, the dataset included the production of Imperial and Riverside counties for all the years 1997-2007. For Texas, the data set included the harvested hectares of individual regulated counties (Archer, Baylor, El Paso, Hudspeth, Knox, McCulloch, Mills, San Saba, Throckmorton and Young) for most of the years 1997-2008; the harvested hectares of the missing years for the El Paso, Hudspeth and Mills counties were estimated by the county mean values for the available years of the period 1997-2008. Lognormal distributions were fitted to the yearly data. The distributions show larger variation and some differences in the mean values for Arizona and California.

Harvested hectares

Symbol:	**A_a**	Unit:	[ha]								
Wheat model		Distribution	Para 1	Para 2	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Arizona	original	UNIFORM (min, max)	28199	30686	29442	2.44%	28224	28324	29442	30561	30661
	updated	LOGNORMAL (mean, std dev)	40190	9409	40191	23.41%	22858	26758	39130	57219	66960
California	original	UNIFORM (min, max)	21107	42825	31966	19.61%	21324	22192	31966	41739	42608
	updated	LOGNORMAL (mean, std dev)	26887	9912	26888	36.90%	10981	14020	25227	45373	57875
Texas	original	UNIFORM (min, max)	16389	167027	91708	47.42%	17895	23921	91708	159495	165520
	updated	LOGNORMAL (mean, std dev)	76478	30628	76477	40.04%	28903	37645	70993	133878	174093

Para = parameter; perc. = percentile.

Proportion that are bunted kernels($Q_{bunt,a}$ [-])

A Beta distribution was fitted to the empirical data obtained from appendix 37 of the USDA APHIS document.

Proportion that are bunted kernels

Symbol:	**Q_bunt_a**	Unit:	[-]									
Wheat model		Distribution	Para 1	Para 2	Para 3	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Total	original	PERT (min, ml, max)	0.00359%	0.0376%	2.500%	0.442%	81%	0.010%	0.034%	0.351%	1.162%	1.536%
Arizona California	updated	BETA (a_1, a_2)	0.03904	87.35		0.0446%	501%	0.000%	0.000%	0.000%	0.212%	1.059%
Texas	updated	BETA (a_1, a_2)	0.02607	123.22		0.0211%	614%	0.000%	0.000%	0.000%	0.0709%	0.565%

Para = parameter; perc. = percentile.

Proportion of bunted kernels exported ($Q_{exp,a}$ [-]).

This parameter was estimated from ten years of historical data (1997-1998 to 2005—2006) from Vocke and Allen (2005), as a proportion of total US exported wheat versus total U.S. wheat production (whilst in the original USDA APHIS model this parameter was calculated as total US exported wheat versus total U.S. wheat use). The between-years variability of $Q_{exp,a}$ was described using a PERT distribution. The parameter was estimated by the minimum, mean and maximum of the empirical data.

Proportion of bunted kernels exported

Symbol:	**Q_exp_a**	Unit:	[-]									
Wheat model		Distribution	Para 1	Para 2	Para 3	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Total	original	PERT (min, ml, max)	43.10%	45.40%	49.20%	45.65%	2.49%	43.49%	43.88%	45.59%	47.62%	48.24%
	updated	PERT (min, ml, max)	41.05%	47.40%	52.94%	47.27%	4.75%	42.46%	43.52%	47.30%	50.90%	51.83%

Para = parameter; perc. = percentile.

Parameters of the wheat for flour sub-pathway

Probability bunted kernels exported to EU country $P_{part,i}$ [-]

The percentages of wheat exported in each European country in the years from 1995 to 2004 were calculated from FAOSTAT data. Beta distributions were fitted to the yearly data of each country by matching the first two moments. It is obvious that the original Beta distribution does not reflect the year by year variability of export to European countries.

Probability bunted kernels exported to EU country

Symbol:	**P_part_i**	Unit:	[-]								
Wheat model		Distribution	Para 1	Para 2	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Austria	original	BETA (n, s)	2729	291815174	0.00094%	1.91%	0.00089%	0.00091%	0.00094%	0.00097%	0.00098%
	updated	BETA (a_1, a_2)	1.552	172238.751	0.00090%	80.33%	0.00004%	0.00011%	0.00072%	0.00232%	0.00335%
Belgium-Luxembourg	original	BETA (n, s)	467171	84817687	0.551%	0.15%	0.549%	0.549%	0.551%	0.552%	0.553%
	updated	BETA (a_1, a_2)	155.944	27992.039	0.554%	7.99%	0.456%	0.483%	0.553%	0.629%	0.662%
Bulgaria	original	BETA (n, s)	124676	86521719	0.144%	0.28%	0.143%	0.143%	0.144%	0.145%	0.145%
	updated	BETA (a_1, a_2)	1.546	1109.328	0.139%	80.33%	0.006%	0.017%	0.111%	0.359%	0.517%
Cyprus	original	BETA (n, s)	385702	291815174	0.132%	0.16%	0.132%	0.132%	0.132%	0.133%	0.133%
	updated	BETA (a_1, a_2)	1.841	1361.697	0.135%	73.63%	0.008%	0.022%	0.112%	0.329%	0.464%
Czech Republic	original	BETA(n, s)	1346	291815174	0.00046%	2.72%	0.00043%	0.00044%	0.00046%	0.00048%	0.00049%
	updated	BETA(a_1, a_2)	5.312	1141548.517	0.00047%	43.38%	0.00013%	0.00019%	0.00044%	0.00084%	0.00106%
Denmark	original	BETA (n, s)	6400	291815174	0.00219%	1.25%	0.00213%	0.00215%	0.00219%	0.00224%	0.00226%
	updated	BETA (a_1, a_2)	1.109	50589.241	0.00219%	94.90%	0.00003%	0.00014%	0.00158%	0.00633%	0.00958%
Estonia	original	BETA (n, s)	274139	291815174	0.0939%	0.19%	0.0935%	0.0936%	0.0939%	0.0942%	0.0944%
	updated	BETA (a_1, a_2)	0.100	110.467	0.0903%	317.03%	0.0000%	0.0000%	0.0005%	0.5247%	1.4299%
Finland	original	BETA (n, s)	13292	291815174	0.00456%	0.87%	0.00446%	0.00449%	0.00456%	0.00462%	0.00465%
	updated	BETA (a_1, a_2)	0.175	3887.926	0.00450%	238.57%	0.00000%	0.00000%	0.00032%	0.02395%	0.05328%
France	original	BETA (n, s)	120719	291815174	0.0414%	0.29%	0.0411%	0.0412%	0.0414%	0.0416%	0.0416%
	updated	BETA (a_1, a_2)	0.654	1655.759	0.0395%	123.57%	0.0000%	0.0005%	0.0220%	0.1377%	0.2263%
Germany	original	BETA (n, s)	204874	291815174	0.0702%	0.22%	0.0698%	0.0700%	0.0702%	0.0705%	0.0706%
	updated	BETA (a_1, a_2)	0.927	1260.537	0.0735%	103.71%	0.0005%	0.0031%	0.0494%	0.2259%	0.3508%
Greece	original	BETA (n, s)	144667	291815174	0.0496%	0.26%	0.0493%	0.0494%	0.0496%	0.0498%	0.0499%
	updated	BETA (a_1, a_2)	0.439	938.384	0.0468%	151.41%	0.0000%	0.0001%	0.0188%	0.1879%	0.3325%
Hungary	original	BETA (n, s)	3991	291815174	0.00137%	1.58%	0.00132%	0.00133%	0.00137%	0.00140%	0.00142%
	updated	BETA (a_1, a_2)	0.248	17617.676	0.00140%	200.47%	0.00000%	0.00000%	0.00024%	0.00682%	0.01374%
Ireland	original	BETA (n, s)	29999	291815174	0.0103%	0.58%	0.0101%	0.0102%	0.0103%	0.0104%	0.0104%
	updated	BETA (a_1, a_2)	0.518	5296.426	0.0098%	138.97%	0.0000%	0.0000%	0.0046%	0.0371%	0.0635%
Italy	original	BETA (n, s)	6178552	291815174	2.117%	0.04%	2.115%	2.116%	2.117%	2.119%	2.119%
	updated	BETA (a_1, a_2)	6.195	280.027	2.164%	39.66%	0.666%	0.965%	2.054%	3.740%	4.628%
Latvia	original	BETA (n, s)	115955	291815174	0.0397%	0.29%	0.0395%	0.0395%	0.0397%	0.0399%	0.0400%
	updated	BETA (a_1, a_2)	0.743	1904.790	0.0390%	115.93%	0.0001%	0.0008%	0.0235%	0.1298%	0.2089%
Lithuania	original	BETA (n, s)	33823	26231938	0.0129%	0.54%	0.0127%	0.0128%	0.0129%	0.0130%	0.0131%
	updated	BETA (a_1, a_2)	0.390	3057.044	0.0127%	159.92%	0.0000%	0.0000%	0.0045%	0.0534%	0.0967%
Malta	original	BETA (n, s)	271857	291815174	0.0932%	0.19%	0.0927%	0.0929%	0.0932%	0.0935%	0.0936%
	updated	BETA (a_1, a_2)	9.176	9764.116	0.0939%	33.00%	0.0370%	0.0493%	0.0905%	0.1499%	0.1804%
Netherlands	original	BETA (n, s)	1277174	291815174	0.438%	0.09%	0.437%	0.437%	0.438%	0.438%	0.439%
	updated	BETA	3.456	779.267	0.442%	53.62%	0.077%	0.136%	0.400%	0.889%	1.166%

		(a_1, a_2)									
Poland	original	BETA (n, s)	281664	291815174	0.097%	0.19%	0.096%	0.096%	0.097%	0.097%	0.097%
	updated	BETA (a_1, a_2)	0.147	160.555	0.091%	260.51%	0.000%	0.000%	0.004%	0.505%	1.182%
Portugal	original	BETA (n, s)	302562	291815174	0.104%	0.18%	0.103%	0.103%	0.104%	0.104%	0.104%
	updated	BETA (a_1, a_2)	0.717	669.891	0.107%	118.26%	0.000%	0.002%	0.063%	0.360%	0.583%
Romania	original	BETA (n, s)	533320	58950849	0.905%	0.14%	0.902%	0.903%	0.905%	0.907%	0.908%
	updated	BETA (a_1, a_2)	3.437	389.346	0.875%	53.63%	0.152%	0.268%	0.793%	1.761%	2.312%
Slovakia	original	BETA (n, s)	62	237451704	0.00003%	12.58%	0.00002%	0.00002%	0.00003%	0.00003%	0.00004%
	updated	BETA (a_1, a_2)	0.823	3070110	0.00003%	110.12%	0.00000%	0.00000%	0.00002%	0.00009%	0.00014%
Slovenia	original	BETA (n, s)	62716	291815174	0.0215%	0.40%	0.0213%	0.0214%	0.0215%	0.0216%	0.0217%
	updated	BETA (a_1, a_2)	0.180	811.285	0.0222%	235.03%	0.0000%	0.0000%	0.0017%	0.1173%	0.2583%
Spain	original	BETA (n, s)	2089107	291815174	0.716%	0.07%	0.715%	0.715%	0.716%	0.717%	0.717%
	updated	BETA (a_1, a_2)	2.926	393.879	0.737%	58.18%	0.104%	0.197%	0.656%	1.554%	2.074%
Sweden	original	BETA (n, s)	51506	291815174	0.0177%	0.44%	0.0175%	0.0175%	0.0177%	0.0178%	0.0178%
	updated	BETA (a_1, a_2)	0.697	3931.783	0.0177%	119.77%	0.0000%	0.0003%	0.0103%	0.0604%	0.0981%
United Kingdom	original	BETA (n, s)	1063577	291815174	0.364%	0.10%	0.364%	0.364%	0.364%	0.365%	0.365%
	updated	BETA (a_1, a_2)	4.934	1322.923	0.372%	44.90%	0.094%	0.145%	0.347%	0.682%	0.864%

BETA(n,s): n=no. part (total metric tons exported to EU country), s= no. total (total metric tons US wheat exported); Para = parameter; perc. = percentile.

Probability exported wheat is a class grown in the US regulated areas $P_{class,i}$ [-]

The percentages of wheat classes HRW, SRW and DUR in relation to total US wheat export to each European country in the years from 1997 to 2007 were calculated from the USDA FAS 1997-2007 statistics reported in Appendix 45 of the USDA APHIS document. No data are available for Austria, Czech Republic, Estonia, Hungary, Ireland, Latvia, Lithuania and Slovakia. Beta distributions were fitted to the yearly data of each country by matching the first two moments. Denmark, Malta and Sweden gave constant 0 % of exported wheat of the considered classes. For Bulgaria a fit to Beta distribution was not possible due to extreme variation. A simple Binomial distribution was used to simulate the empirical values.

Probability exported wheat is a class grown in the US regulated areas

Symbol:	**P_class_i**	Unit:	[-]								
Wheat model		Distribution	Para 1	Para 2	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Austria	no distribution										
Belgium-Luxembourg	original	BETA(n, s)	234600	1256800	18.67%	0.19%	18.59%	18.61%	18.67%	18.72%	18.75%
	updated	BETA (a_1, a_2)	1.192	5.880	16.85%	78.18%	0.38%	1.51%	13.70%	43.02%	56.91%
Bulgaria	original	BETA (n, s)	83400	83400	100.00%	0.00%	99.99%	100.00%	100.00%	100.00%	100.00%
	updated	BINOMIAL (n, p)	1.000	0.231	23.08%	182.57%	0.00%	0.00%	0.00%	100.00%	100.00%
Cyprus	original	BETA (n, s)	114200	283900	40.23%	0.23%	40.01%	40.07%	40.23%	40.38%	40.44%
	updated	BETA (a_1, a_2)	2.077	4.249	32.84%	52.85%	3.43%	7.81%	30.93%	64.40%	76.39%
Czech Republic	no distribution										
Denmark	original	BETA (n, s)	0	1300	0.08%	99.92%	0.00%	0.00%	0.05%	0.23%	0.35%
	updated	CONSTANT(c)	0		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Estonia	no distribution									
Finland	original	BETA (n, s)	6600	34100	19.36%	1.11%	18.86%	19.01%	19.36%	19.71%	19.86%
	updated	BETA (a_1, a_2)	0.237	1.846	11.38%	158.98%	0.00%	0.00%	2.45%	53.68%	78.66%
France	original	BETA (n, s)	1400	8200	17.08%	2.43%	16.13%	16.40%	17.08%	17.77%	18.06%
	updated	BETA (a_1, a_2)	0.021	0.186	10.32%	268.33%	0.00%	0.00%	0.00%	98.05%	100.00%
Germany	original	BETA (n, s)	108000	154400	69.95%	0.17%	69.68%	69.76%	69.95%	70.14%	70.22%
	updated	BETA (a_1, a_2)	0.210	0.191	52.34%	80.62%	0.00%	0.00%	57.57%	100.00%	100.00%
Greece	original	BETA (n, s)	2400	40400	5.94%	1.98%	5.67%	5.75%	5.94%	6.14%	6.22%
	updated	BETA (a_1, a_2)	0.259	18.664	1.37%	189.81%	0.00%	0.00%	0.27%	6.56%	12.62%
Hungary	no distribution										
Ireland	no distribution										
Italy	original	BETA (n, s)	3666300	8107200	45.22%	0.04%	45.18%	45.19%	45.22%	45.25%	45.26%
	updated	BETA (a_1, a_2)	11.494	13.898	45.27%	21.41%	23.80%	29.51%	45.14%	61.44%	67.78%
Latvia	no distribution										
Lithuania	no distribution										
Malta	original	BETA (n, s)	0	306600	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	updated	CONSTANT(c)	0		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Netherlands	original	BETA (n, s)	131900	303700	43.43%	0.21%	43.22%	43.28%	43.43%	43.58%	43.64%
	updated	BETA (a_1, a_2)	0.407	0.853	32.29%	96.36%	0.00%	0.08%	21.84%	92.34%	98.80%
Poland	original	BETA (n, s)	123300	156300	78.89%	0.13%	78.65%	78.72%	78.89%	79.06%	79.13%
	updated	BETA (a_1, a_2)	0.016	0.043	27.52%	157.70%	0.00%	0.00%	0.00%	100.00%	100.00%
Portugal	original	BETA (n, s)	12900	466500	2.77%	0.87%	2.71%	2.73%	2.77%	2.81%	2.82%
	updated	BETA (a_1, a_2)	0.132	8.686	1.50%	258.90%	0.00%	0.00%	0.04%	8.59%	19.74%
Romania	original	BETA (n, s)	556800	1099400	50.65%	0.09%	50.53%	50.57%	50.65%	50.72%	50.76%
	updated	BETA (a_1, a_2)	0.048	0.260	15.48%	204.35%	0.00%	0.00%	0.00%	98.80%	100.00%
Slovakia	no distribution										
Slovenia	original	BETA (n, s)	41000	79800	51.38%	0.34%	50.97%	51.09%	51.38%	51.67%	51.79%
	updated	BETA (a_1, a_2)	0.047	0.256	15.60%	203.75%	0.00%	0.00%	0.00%	98.90%	100.00%
Spain	original	BETA (n, s)	762300	1994800	38.21%	0.09%	38.13%	38.16%	38.21%	38.27%	38.29%
	updated	BETA (a_1, a_2)	0.329	2.345	12.30%	139.30%	0.00%	0.00%	4.45%	51.00%	73.60%
Sweden	original	BETA (n, s)	0	101900	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	updated	CONSTANT(c)	0		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
United Kingdom	original	BETA (n, s)	10200	1348400	0.76%	0.99%	0.74%	0.74%	0.76%	0.77%	0.77%
	updated	BETA (a_1, a_2)	0.092	9.985	0.92%	312.17%	0.00%	0.00%	0.00%	5.48%	14.72%

BETA(n,s): n=no. part (total exported metric tons of wheat classes grown in US regulated areas), s= no. total (total metric tons exported wheat); Para = parameter; perc. = percentile.

Teliospores per bunted kernel T_{bunt} [-]

This parameter was estimated by a PERT distribution, where the minimum and maximum values were obtained from the study by Rattan and Aujla (1990) on Karnal bunt infected wheat grains of varying disease intensity, where the teliospores load was measured for 30 grains in each category of infection. The minimum was set as 1.13×10^5 teliospores per bunted kernel, i.e. the spore load for incipient tip infection, while the maximum was set as 61.20×10^5 teliospores per bunted kernel, i.e. the spore load for the maximum grade of infection (whole grain converted into spore mass leaving pericarp intact only). The most likely value was set equal to that of the USDA APHIS document, i.e. 3.78667× 10^5 teliospores per bunted kernel (Goates, 2007, 2008).

Teliospores per bunted kernel

Symbol:	**T_bunt**	Unit:	[-]									
Wheat model		Distribution	Para 1	Para 2	Para 3	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Total	original	PERT (min, ml, max)	264000	378667	498667	379556	11.68%	287799	307005	379346	452829	472865
	updated	PERT (min, ml, max)	113000	378667	6120000	1291274	69.82%	139381	219400	1084034	3073576	3950765

Para = parameter; perc. = percentile.

Proportion of teliospores spilled from port to storage processing facility ($R_{port,stor}$ [-])

This parameter was estimated by a uniform distribution with minimum 0.003 and maximum 0.004, where 0.003 is an estimate of grain spillage/losses with efficient discharge operation and 0.04 is a technically acceptable grain spillage/loss at an Italian harbour (Italmopa, 2010).

Proportion of teliospores spilled from port to storage processing facility

Symbol:	**R_port_stor**	Unit:	[-]									
Wheat model		Distribution	Para 1	Para 2	Para 3	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Total	original	PERT (min, ml, max)	0.0000%	0.0100%	0.0200%	0.0100%	37.80%	0.0021%	0.0038%	0.0100%	0.0162%	0.0179%
	updated	UNIFORM (min, max)	0.3000%	0.4000%		0.3500%	8.25%	0.3010%	0.3050%	0.3500%	0.3950%	0.3990%

Para = parameter; perc. = percentile.

Proportion of teliospores spilled from storage to mill processing facility ($R_{stor,mill}$ [-])

This parameter was estimated by a uniform distribution with minimum 0.0006 and maximum 0.001, where 0.006 is an estimate of grain spillage/losses between port storage/first storage and mill with efficient transportation and 0.001 is an estimate of grain spillage/loss between port storage/first storage and mill for Italy (Italmopa, 2010).

Proportion of teliospores spilled from storage to mill processing facility

Symbol:	**R_stor_mill**	Unit:	[-]									
Wheat model		Distribution	Para 1	Para 2	Para 3	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Total	original	PERT (min, ml, max)	0.0000%	0.0100%	0.0200%	0.0100%	37.80%	0.0021%	0.0038%	0.0100%	0.0162%	0.0179%
	updated	UNIFORM (min, max)	0.0600%	0.1000%		0.0800%	14.43%	0.0604%	0.0620%	0.0800%	0.0980%	0.0996%

Para = parameter; perc. = percentile.

Probability house filter fails P_{fail} [-]

This parameter was estimated by a PERT distribution with minimum value 0.00, most likely value 0.04 and maximum value 0.1 (Martinez et al., 1998; Peterson, 2006).

Probability house filter fails

Symbol:	**P_fail**	Unit:	[-]									
Wheat model		Distribution	Para 1	Para 2	Para 3	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Total	original	PERT (min, ml, max)	0.00%	4.00%	9.10%	4.18%	40.98%	0.77%	1.44%	4.14%	7.08%	7.92%
	updated	PERT (min, ml, max)	0.00%	4.00%	10.00%	4.33%	43.22%	0.71%	1.39%	4.25%	7.54%	8.53%

Para = parameter; perc. = percentile.

Parameters of the millfeed products sub-pathway

Proportion of teliospores spilled from mill to feedlot storage Rmill,stor [-]

This parameter was estimated fitting a Beta distribution to the industry estimates for losses in millfeed distribution in China (US Wheat Associates/Beijing) presented in appendix 50 of the USDA APHIS document by matching moments.

Proportion of teliospores spilled from mill to feedlot storage

Symbol:	**R_mill_stor**	Unit:	[-]								
Wheat model		Distribution	Para 1	Para 2	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Total	original	UNIFORM (min, max)	0.100%	1.000%	0.550%	47.238%	0.109%	0.145%	0.550%	0.955%	0.991%
	updated	BETA (a_1, a_2)	8.596	3149.082	0.272%	34.076%	0.103%	0.140%	0.262%	0.440%	0.532%

Para = parameter; perc. = percentile.

Proportion of teliospores spilled from feedlot storage to feedlots Rstor,feed [-]

The distribution of $R_{mill,stor}$ is used for this parameter.

Probability manure dispersed to wheat production area $P_{manu,i}$ *[-]*

A Beta distribution was fitted for each EU country to the yearly ratios between harvested wheat hectares and total agriculture area using the data reported in appendixes 55 and 56 of the USDA APHIS document. The distribution for Belgium/Luxembourg was not updated due to missing yearly data.

Probability manure dispersed to wheat production area

Symbol:	**P_manu_i**	Unit:	[-]								
Wheat model		Distribution	Para 1	Para 2	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Austria	original	BETA(n, s)	275390	3411000	8.07%	0.18%	8.04%	8.05%	8.07%	8.10%	8.11%
	updated	BETA (a_1, a_2)	220.01	2534.32	7.99%	6.47%	6.83%	7.16%	7.98%	8.85%	9.23%
Belgium-Luxembourg	original	BETA (n, s)	213769	1506000	14.19%	0.20%	14.13%	14.15%	14.19%	14.24%	14.26%
	not updated										
Bulgaria	original	BETA (n, s)	1096486	5774500	18.99%	0.09%	18.95%	18.96%	18.99%	19.02%	19.03%
	updated	BETA (a_1, a_2)	20.20	83.38	19.50%	19.87%	11.41%	13.48%	19.31%	26.20%	29.31%
Cyprus	original	BETA (n, s)	5680	146000	3.89%	1.30%	3.77%	3.81%	3.89%	3.97%	4.01%
	updated	BETA (a_1, a_2)	38.66	963.74	3.86%	15.77%	2.58%	2.91%	3.83%	4.91%	5.40%
Czech Republic	original	BETA (n, s)	847796	4278300	19.82%	0.10%	19.77%	19.78%	19.82%	19.85%	19.86%
	updated	BETA (a_1, a_2)	59.96	242.09	19.85%	11.54%	14.82%	16.20%	19.78%	23.73%	25.46%
Denmark	original	BETA (n, s)	653089	2679000	24.38%	0.11%	24.32%	24.33%	24.38%	24.42%	24.44%
	updated	BETA (a_1, a_2)	256.19	798.72	24.29%	5.43%	21.29%	22.14%	24.27%	26.48%	27.42%
Estonia	original	BETA (n, s)	65617	957000	6.86%	0.38%	6.80%	6.81%	6.86%	6.90%	6.92%
	updated	BETA (a_1, a_2)	17.45	242.47	6.71%	23.08%	3.61%	4.37%	6.60%	9.44%	10.78%
Finland	original	BETA (n, s)	159220	2271000	7.01%	0.24%	6.97%	6.98%	7.01%	7.04%	7.05%
	updated	BETA (a_1, a_2)	23.99	351.35	6.39%	19.72%	3.81%	4.46%	6.32%	8.59%	9.66%
France	original	BETA (n, s)	5114376	29854000	17.13%	0.04%	17.12%	17.12%	17.13%	17.14%	17.15%
	updated	BETA	709.21	3452.58	17.04%	3.42%	15.71%	16.09%	17.04%	18.01%	18.42%

		(a_1, a_2)									
Germany	original	BETA (n, s)	2887353	17192000	16.79%	0.05%	16.77%	16.78%	16.79%	16.81%	16.82%
	updated	BETA (a_1, a_2)	188.46	956.97	16.45%	6.66%	13.99%	14.69%	16.43%	18.29%	19.08%
Greece	original	BETA (n, s)	856638	8785000	9.75%	0.10%	9.73%	9.73%	9.75%	9.77%	9.77%
	updated	BETA (a_1, a_2)	616.58	5621.91	9.88%	3.82%	9.02%	9.27%	9.88%	10.51%	10.78%
Hungary	original	BETA (n, s)	1111582	6051100	18.37%	0.09%	18.33%	18.34%	18.37%	18.40%	18.41%
	updated	BETA (a_1, a_2)	35.94	160.48	18.30%	15.04%	12.39%	13.96%	18.19%	23.00%	25.15%
Ireland	original	BETA (n, s)	88470	4395000	2.01%	0.33%	2.00%	2.00%	2.01%	2.02%	2.03%
	updated	BETA (a_1, a_2)	59.72	2970.66	1.97%	12.81%	1.43%	1.57%	1.96%	2.40%	2.60%
Italy	original	BETA (n, s)	2326567	15467000	15.04%	0.06%	15.02%	15.03%	15.04%	15.06%	15.06%
	updated	BETA (a_1, a_2)	1614.55	9011.46	15.19%	2.29%	14.39%	14.63%	15.19%	15.77%	16.01%
Latvia	original	BETA (n, s)	160347	2500000	6.41%	0.24%	6.38%	6.39%	6.41%	6.44%	6.45%
	updated	BETA (a_1, a_2)	300.77	4510.71	6.25%	5.58%	5.47%	5.69%	6.24%	6.83%	7.09%
Lithuania	original	BETA (n, s)	353390	3497000	10.11%	0.16%	10.07%	10.08%	10.11%	10.13%	10.14%
	updated	BETA (a_1, a_2)	437.40	3911.94	10.06%	4.54%	9.02%	9.32%	10.05%	10.82%	11.14%
Malta	original	BETA (n, s)	2178	10000	21.79%	1.89%	20.83%	21.11%	21.78%	22.47%	22.75%
	updated	BETA (a_1, a_2)	14.33	50.38	22.15%	23.13%	11.60%	14.23%	21.86%	31.04%	35.17%
Netherlands	original	BETA (n, s)	132970	1959000	6.79%	0.26%	6.75%	6.76%	6.79%	6.82%	6.83%
	updated	BETA (a_1, a_2)	100.93	1406.82	6.69%	9.61%	5.28%	5.67%	6.67%	7.78%	8.27%
Poland	original	BETA (n, s)	2477887	18101000	13.69%	0.06%	13.67%	13.68%	13.69%	13.70%	13.71%
	updated	BETA (a_1, a_2)	1711.61	10437.82	14.09%	2.24%	13.36%	13.57%	14.09%	14.61%	14.83%
Portugal	original	BETA (n, s)	208027	3845000	5.41%	0.21%	5.38%	5.39%	5.41%	5.43%	5.44%
	updated	BETA (a_1, a_2)	21.02	356.33	5.57%	21.17%	3.18%	3.77%	5.49%	7.64%	8.65%
Romania	original	BETA (n, s)	2057902	14797600	13.91%	0.06%	13.89%	13.89%	13.91%	13.92%	13.93%
	updated	BETA (a_1, a_2)	24.03	155.07	13.42%	18.93%	8.13%	9.48%	13.28%	17.82%	19.89%
Slovakia	original	BETA (n, s)	385874	2444100	15.79%	0.15%	15.73%	15.75%	15.79%	15.83%	15.84%
	updated	BETA (a_1, a_2)	41.00	216.31	15.93%	14.30%	11.04%	12.34%	15.84%	19.82%	21.60%
Slovenia	original	BETA (n, s)	34661	514000	6.74%	0.52%	6.66%	6.69%	6.74%	6.80%	6.83%
	updated	BETA (a_1, a_2)	246.93	3276.07	7.01%	6.14%	6.04%	6.32%	7.00%	7.73%	8.04%
Spain	original	BETA (n, s)	2197489	29976000	7.33%	0.06%	7.32%	7.32%	7.33%	7.34%	7.34%
	updated	BETA (a_1, a_2)	120.79	1526.94	7.33%	8.76%	5.91%	6.30%	7.31%	8.41%	8.90%
Sweden	original	BETA (n, s)	366285	3227000	11.35%	0.16%	11.31%	11.32%	11.35%	11.38%	11.39%
	updated	BETA (a_1, a_2)	46.48	363.57	11.33%	13.80%	7.98%	8.87%	11.27%	14.01%	15.24%
United Kingdom	original	BETA (n, s)	1931800	17245000	11.20%	0.07%	11.18%	11.19%	11.20%	11.21%	11.22%
	updated	BETA (a_1, a_2)	167.73	1326.42	11.23%	7.27%	9.40%	9.91%	11.21%	12.60%	13.20%

BETA (n,s): n=no. part (wheat area), s= no. total (total agricultural area); Para = parameter; perc. = percentile

Probability feed lot manure used as fertilizer P_{fert} *[-]*

This parameter was estimated by a PERT distribution with minimum, maximum and most likely values respectively set as 0.20, 1.00 and 0.9512, respectively from the minimum, maximum and general average estimates of the utilization of different types of animal manure (slurry/liquid; solid manure by cattle/pigs; poultry manure) on agriculture land (arable crops plus grassland) for 20 EU countries (Menzi, 2002).

Probability feed lot manure used as fertilizer

Symbol:	**P_fert**	Unit:	[-]									
Wheat model		Distribution	Para 1	Para 2	Para 3	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Total	original	PERT (min, ml, max)	15.5%	27.0%	38.5%	27.0%	16.10%	17.9%	19.9%	27.0%	34.1%	36.1%
	updated	PERT (min, ml, max)	20.0%	95.1%	100.0%	83.4%	14.70%	47.8%	59.3%	86.1%	98.3%	99.5%

Para = parameter; perc. = percentile.

Parameters of the spillage sub-pathway

Probability spilled teliospores from port to grain storage dispersed to wheat production area $P_{port,i}$ [-]

A Beta distribution was fitted for each EU country to the yearly ratios between harvested wheat hectares and total country area using the data reported in appendixes 55 and 56 of the USDA APHIS document by matching moments.

Probability spilled teliospores from port to grain storage dispersed to wheat production area

Symbol:	**P_port_i**	Unit:	[-]								
Wheat model		Distribution	Para 1	Para 2	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Austria	original	BETA (n, s)	275390	8387000	3.28%	0.19%	3.27%	3.27%	3.28%	3.29%	3.30%
	updated	BETA (a_1, a_2)	270.529	7968.416	3.28%	5.98%	2.84%	2.97%	3.28%	3.61%	3.76%
Belgium-Luxembourg	original	BETA (n, s)	213769	3311400	6.46%	0.21%	6.42%	6.43%	6.46%	6.48%	6.49%
	updated	BETA (a_1, a_2)	207.744	3010.327	6.46%	6.71%	5.49%	5.76%	6.45%	7.18%	7.50%
Bulgaria	original	BETA (n, s)	1096486	11091000	9.89%	0.09%	9.87%	9.87%	9.89%	9.90%	9.91%
	updated	BETA (a_1, a_2)	35.342	322.141	9.89%	15.94%	6.55%	7.43%	9.81%	12.60%	13.87%
Cyprus	original	BETA (n, s)	5680	925000	0.61%	1.32%	0.60%	0.60%	0.61%	0.63%	0.63%
	updated	BETA (a_1, a_2)	51.333	8308.392	0.61%	13.91%	0.43%	0.48%	0.61%	0.76%	0.83%
Czech Republic	original	BETA (n, s)	847796	7886600	10.75%	0.10%	10.72%	10.73%	10.75%	10.77%	10.78%
	updated	BETA (a_1, a_2)	83.648	694.485	10.75%	10.33%	8.32%	8.98%	10.72%	12.63%	13.47%
Denmark	original	BETA (n, s)	653089	4309400	15.16%	0.11%	15.11%	15.13%	15.15%	15.18%	15.20%
	updated	BETA (a_1, a_2)	306.338	1715.030	15.15%	5.26%	13.35%	13.86%	15.14%	16.49%	17.06%
Estonia	original	BETA (n, s)	65617	4522600	1.45%	0.39%	1.44%	1.44%	1.45%	1.46%	1.46%
	updated	BETA (a_1, a_2)	30.010	2038.411	1.45%	18.12%	0.91%	1.05%	1.44%	1.91%	2.13%
Finland	original	BETA (n, s)	159220	33814500	0.47%	0.25%	0.47%	0.47%	0.47%	0.47%	0.47%
	updated	BETA (a_1, a_2)	15.548	3286.528	0.47%	25.30%	0.24%	0.29%	0.46%	0.68%	0.79%
France	original	BETA (n, s)	5114376	54703000	9.35%	0.04%	9.34%	9.34%	9.35%	9.36%	9.36%
	updated	BETA (a_1, a_2)	779.642	7559.351	9.35%	3.41%	8.62%	8.83%	9.35%	9.88%	10.10%
Germany	original	BETA (n, s)	2887353	35702100	8.09%	0.06%	8.08%	8.08%	8.09%	8.09%	8.10%
	updated	BETA (a_1, a_2)	186.142	2115.498	8.09%	7.03%	6.82%	7.17%	8.08%	9.04%	9.46%
Greece	original	BETA (n, s)	856638	13194000	6.49%	0.10%	6.48%	6.48%	6.49%	6.50%	6.51%
	updated	BETA (a_1, a_2)	3244.988	46734.568	6.49%	1.70%	6.24%	6.31%	6.49%	6.67%	6.75%
Hungary	original	BETA (n, s)	1111582	9303000	11.95%	0.09%	11.92%	11.93%	11.95%	11.97%	11.97%
	updated	BETA (a_1, a_2)	50.510	372.214	11.95%	13.19%	8.55%	9.46%	11.89%	14.64%	15.87%
Ireland	original	BETA (n, s)	88470	7028000	1.26%	0.33%	1.25%	1.25%	1.26%	1.27%	1.27%
	updated	BETA (a_1, a_2)	65.976	5175.095	1.26%	12.23%	0.93%	1.02%	1.25%	1.52%	1.64%
Italy	original	BETA (n, s)	2326567	30123000	7.72%	0.06%	7.71%	7.72%	7.72%	7.73%	7.73%

	updated	BETA (a_1, a_2)	691.480	8261.385	7.72%	3.65%	7.08%	7.26%	7.72%	8.19%	8.39%
Latvia	original	BETA (n, s)	160347	6458900	2.48%	0.25%	2.47%	2.47%	2.48%	2.49%	2.50%
	updated	BETA (a_1, a_2)	145.953	5733.134	2.48%	8.17%	2.03%	2.16%	2.48%	2.83%	2.98%
Lithuania	original	BETA (n, s)	353390	6520000	5.42%	0.16%	5.40%	5.41%	5.42%	5.43%	5.44%
	updated	BETA (a_1, a_2)	511.306	8922.225	5.42%	4.30%	4.89%	5.04%	5.42%	5.81%	5.98%
Malta	original	BETA (n, s)	2178	31600	6.90%	2.07%	6.57%	6.66%	6.89%	7.13%	7.23%
	updated	BETA (a_1, a_2)	28.992	391.623	6.89%	17.90%	4.33%	4.99%	6.82%	9.03%	10.05%
Netherlands	original	BETA (n, s)	132970	4152600	3.20%	0.27%	3.18%	3.19%	3.20%	3.22%	3.22%
	updated	BETA (a_1, a_2)	116.366	3517.706	3.20%	9.12%	2.56%	2.74%	3.19%	3.70%	3.92%
Poland	original	BETA (n, s)	2477887	31268500	7.92%	0.06%	7.91%	7.92%	7.92%	7.93%	7.94%
	updated	BETA (a_1, a_2)	244.703	2843.210	7.92%	6.13%	6.83%	7.14%	7.92%	8.74%	9.09%
Portugal	original	BETA (n, s)	208027	9239100	2.25%	0.22%	2.24%	2.24%	2.25%	2.26%	2.26%
	updated	BETA (a_1, a_2)	30.688	1332.258	2.25%	17.84%	1.42%	1.63%	2.23%	2.95%	3.29%
Romania	original	BETA (n, s)	2057902	23750000	8.66%	0.07%	8.65%	8.66%	8.66%	8.67%	8.68%
	updated	BETA (a_1, a_2)	28.440	299.780	8.66%	17.89%	5.44%	6.26%	8.58%	11.35%	12.63%
Slovakia	original	BETA (n, s)	385874	4884500	7.90%	0.15%	7.87%	7.88%	7.90%	7.92%	7.93%
	updated	BETA (a_1, a_2)	54.871	639.701	7.90%	12.95%	5.70%	6.29%	7.86%	9.65%	10.45%
Slovenia	original	BETA (n, s)	34661	2027300	1.71%	0.53%	1.69%	1.69%	1.71%	1.72%	1.73%
	updated	BETA (a_1, a_2)	143.505	8250.090	1.71%	8.27%	1.40%	1.48%	1.71%	1.95%	2.06%
Spain	original	BETA (n, s)	2197489	50478200	4.35%	0.07%	4.35%	4.35%	4.35%	4.36%	4.36%
	updated	BETA (a_1, a_2)	164.182	3607.210	4.35%	7.63%	3.62%	3.82%	4.35%	4.91%	5.16%
Sweden	original	BETA (n, s)	366285	44996400	0.81%	0.16%	0.81%	0.81%	0.81%	0.82%	0.82%
	updated	BETA (a_1, a_2)	69.338	8448.559	0.81%	11.96%	0.60%	0.66%	0.81%	0.98%	1.06%
United Kingdom	original	BETA (n, s)	1931800	24482000	7.89%	0.07%	7.88%	7.88%	7.89%	7.90%	7.90%
	updated	BETA (a_1, a_2)	187.415	2187.726	7.89%	7.01%	6.66%	7.00%	7.88%	8.82%	9.23%

BETA (n,s): n=no. part (wheat area), s= no. total (total area); Para = parameter; perc. = percentile.

Probability spilled teliospores from grain storage to mill dispersed to wheat production area $P_{stor,i}$ [-]

The distributions of $P_{port,i}$ were used also for these parameters.

Probability teliospores released during milling dispersed to wheat production area $P_{mill,i}$ [-]

The distributions of $P_{port,i}$ were used also for these parameters.

Probability spilled teliospores from mill to feedlot storage dispersed to wheat production area ($P_{feedlot,i}$ [-])

The distributions of $P_{port,i}$ were used also for these parameters.

Probability spilled teliospores from feedlot storage to feedlot dispersed to wheat production area ($P_{feed,i}$ [-])

The distributions of $P_{port,i}$ were used also for these parameters.

Parameters of the introduction sub-pathway

Wheat hectares $A_{wheat,i}$ *[ha]*

A normal distribution was fitted as the best fit to the yearly data from 1996 to 2005 for each EU country by maximum likelihood estimation.

Wheat hectares

Symbol:	**A_wheat_i**	Unit:	[ha]									
Wheat model		Distribution	parameter 1	parameter 2	parameter 3	mean	CV	1%-percentile	5%-percentile	median	95%-percentile	99%-percentile
Austria	original	PERT (min, ml, max)	247602	275390	293806	273828	3.16%	254389	258984	274195	287400	290519
	updated	NORMAL (mean, sted dev)	275390	16465		275390	5.98%	237082	248297	275388	302461	313676
Belgium-Luxembourg	original	PERT (min, ml, max)	190925	213769	225770	211962	3.04%	196920	200664	212386	221788	223840
	updated	NORMAL (mean, sted dev)	213769	14342		213768	6.71%	180380	190170	213767	237352	247124
Bulgaria	original	PERT (min, ml, max)	841260	1096486	1368900	1099349	9.07%	893698	936547	1098658	1264369	1309789
	updated	NORMAL (mean, sted dev)	1096486	174843		1096489	15.94%	689229	808762	1096484	1384056	1503185
Cyprus	original	PERT(min, ml, max)	3700	5680	6600	5503	9.66%	4238	4561	5545	6302	6460
	updated	NORMAL (mean, sted dev)	5680	790		5680	13.91%	3840	4379	5680	6980	7518
Czech Republic	original	PERT (min, ml, max)	798610	847796	970435	860038	3.62%	805583	814104	857157	915855	935644
	updated	NORMAL (mean, sted dev)	847796	87516		847796	10.32%	644196	703827	847789	991718	1051327
Denmark	original	PERT (min, ml, max)	576625	653089	689000	646330	3.19%	597394	609830	647916	677334	683513
	updated	NORMAL (mean, sted dev)	653089	34362		653089	5.26%	573042	596551	653085	709584	733001
Estonia	original	PERT (min, ml, max)	45927	65617	86900	65883	11.75%	49955	53263	65819	78712	82253
	updated	NORMAL (mean, sted dev)	65617	11888		65616	18.12%	37917	46052	65617	85162	93267
Finland	original	PERT (min, ml, max)	112500	159220	225200	162430	13.03%	121059	128963	161667	198489	209359
	updated	NORMAL (mean, sted dev)	159220	40278		159220	25.30%	65442	92966	159218	225447	252884
France	original	PERT (min, ml, max)	4766560	5114376	5288000	5085344	1.89%	4859293	4916141	5092175	5230940	5260741
	updated	NORMAL (mean, sted dev)	5114376	174383		5114380	3.41%	4708620	4827476	5114366	5401063	5519606
Germany	original	PERT (min, ml, max)	2594418	2887353	3187800	2888605	3.88%	2655578	2704683	2888301	3073442	3123477
	updated	NORMAL (mean, sted dev)	2887353	202848		2887347	7.03%	2415324	2553658	2887337	3220885	3358899
Greece	original	PERT (min, ml, max)	826700	856638	876400	854942	1.09%	834023	838974	855341	869531	872885
	updated	NORMAL (mean, sted dev)	856638	14542		856638	1.70%	822759	832715	856634	880544	890414
Hungary	original	PERT (min, ml, max)	734100	1111582	1247569	1071333	8.60%	843817	904687	1080771	1205472	1229148

	updated	NORMAL (mean, sted dev)	1111582	146591		1111577	13.19%	770379	870446	1111579	1352566	1452393
Ireland	original	PERT (min, ml, max)	68100	88470	102700	87447	7.43%	72990	76362	87687	97696	100100
	updated	NORMAL (mean, sted dev)	88470	10822		88470	12.23%	63260	70667	88469	106268	113629
Italy	original	PERT (min, ml, max)	2127866	2326567	2415535	2308279	2.28%	2182512	2214790	2312571	2386918	2402219
	updated	NORMAL (mean, sted dev)	2326567	84986		2326570	3.65%	2128698	2186747	2326566	2466286	2524154
Latvia	original	PERT (min, ml, max)	146000	160347	189000	162731	4.87%	148249	150714	162170	176678	181335
	updated	NORMAL (mean, sted dev)	160347	13106		160347	8.17%	129854	138784	160346	181901	190825
Lithuania	original	PERT (min, ml, max)	333700	353390	375600	353810	2.24%	337653	340972	353709	366983	370673
	updated	NORMAL (mean, sted dev)	353390	15198		353390	4.30%	317991	328381	353387	378381	388738
Malta	original	PERT(min, ml, max)	1100	2178	2400	2035	10.84%	1450	1621	2069	2335	2376
	updated	NORMAL (mean, sted dev)	2178	390		2178	17.90%	1270	1537	2178	2819	3084
Netherlands	original	PERT(min, ml, max)	102195	132970	143700	129629	5.73%	111194	116165	130410	140394	142263
	updated	NORMAL (mean, sted dev)	132970	12126		132969	9.12%	104741	113022	132969	152911	161135
Poland	original	PERT (min, ml, max)	2233957	2477887	2635097	2463434	3.05%	2294169	2334356	2466840	2580718	2607375
	updated	NORMAL (mean, sted dev)	2477887	151972		2477889	6.13%	2124214	2227901	2477854	2727737	2831227
Portugal	original	PERT(min, ml, max)	148858	208027	276764	209622	11.52%	160618	170580	209239	249942	261349
	updated	NORMAL (mean, sted dev)	208027	37113		208028	17.84%	121610	146981	208020	269045	294315
Romania	original	PERT (min, ml, max)	1411770	2057902	2540160	2030590	10.45%	1563650	1670642	2037009	2368184	2449510
	updated	NORMAL (mean, sted dev)	2057902	368231		2057889	17.89%	1201128	1452045	2057835	2663457	2913848
Slovakia	original	PERT (min, ml, max)	295832	385874	445278	380768	7.35%	317884	332749	381965	424624	434683
	updated	NORMAL (mean, sted dev)	385874	49956		385873	12.95%	269555	303669	385863	468022	501910
Slovenia	original	PERT (min, ml, max)	30086	34661	39335	34677	5.04%	31042	31809	34673	37557	38337
	updated	NORMAL (mean, sted dev)	34661	2868		34661	8.28%	27984	29942	34660	39376	41324
Spain	original	PERT (min, ml, max)	1912560	2197489	2422400	2187485	4.39%	1978150	2025537	2189833	2341251	2379190
	updated	NORMAL (mean, sted dev)	2197489	167703		2197489	7.63%	1806970	1921537	2197467	2473327	2587211
Sweden	original	PERT (min, ml, max)	275400	366285	411348	358648	6.98%	299719	314520	360440	396557	404288
	updated	NORMAL (mean, sted dev)	366285	43806		366283	11.96%	264334	294230	366285	438312	468077
United Kingdom	original	PERT (min, ml, max)	1635000	1931800	2086000	1908034	4.37%	1713339	1761803	1913614	2034949	2061311

	updated	NORMAL (mean, sted dev)	1931800	135400	1931801	7.01%	1616419	1709052	1931786	2154459	2246324

2.2.6.2. New probability distributions for parameters of the US desert durum wheat for grain model

The original USDA APHIS desert durum wheat model was reconstructed starting from the USDA APHIS original wheat model (see Section 2.2.5). For the desert durum updated model, generally the same set of alternative distributions and parameters of the updated wheat for grain model as listed above were used. Particularly, for the following parameters, the values and distribution remain the same as for the updated wheat model: $A_{pos,a}$, A_a, $Q_{bunt,a}$, $Q_{exp,a}$, T_{bunt}, $R_{port,stor}$, $R_{stor,mill}$, P_{fail}, $R_{mill,stor}$, $R_{stor,feed}$, $P_{manu,I}$, P_{fert}, $P_{port,I}$, $P_{stor,I}$, $P_{mill,I}$, $P_{feedlot,I}$, $P_{feed,I}$, $A_{wheat,i}$. Only four parameters were updated specifically for the desert durum updated model: W_a, U_w, and $P_{part,i}$ and $P_{class,i}$. All other parameters and distributions remain unchanged with respect to the original USDA APHIS model.

Parameters of the grain export sub-pathway

Bushels/yr of kernels from the affected counties in Arizona, California, Texas (W_a, [1/y])

For this parameter, the available production data in bushels/year of durum wheat from individual regulated counties of Arizona and California were extracted from the Quick Stats webpage of the USDA National Agricultural Statistics Service (USDA NASS, online) for the period 1997-2008. For Arizona, the dataset included the production of Lapaz, Maricopa, Pinal and Yuma counties for the years 1997-2007; for the year 2001 missing data for Pinal were estimated by the county mean value of reported years. For California, the dataset included the production of Imperial and Riverside counties for all the years 1997-2008, other than for Riverside county 2008 durum wheat production which was estimated by the county mean value of reported years. A lognormal distribution was fitted to the data by maximum likelihood estimation.

Bushels per year of durum kernels from the affected counties in Arizona, California

Symbol:	**W_a**	Unit:	[bushels / y]								
Durum model		Distribution	Para 1	Para 2	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Arizona	original	UNIFORM (min, max)	8,214,649	8,428,484	8321567	0.74%	8216787	8225341	8321567	8417792	8426346
	updated	LOGNORMAL (mean, std dev)	8479829	1816711	8479829	21.42%	5065428	5852134	8291677	11748177	13572774
California	original	UNIFORM (min, max)	4,615,084	7,605,222	6110153	14.13%	4644985	4764591	6110153	7455715	7575321
	updated	LOGNORMAL (mean, std dev)	5753643	2417665	5753643	42.02%	2076045	2732640	5304383	10296444	13552920

Para = parameter; perc. = percentile.

Kg per bushel (U_w, [kg])

Test weights in lb/bu of Desert durum wheat varieties were obtained from Arizona/California Desert Durum combined crop analyses for the years 2001-2009 (California Wheat Commission, 2001, 2002, 2003, 2004, 2005b, 2006b, 2007b, 2008b, 2009b) and converted into kg/bu. A Weibull distribution was used as best fit to the data.

kg per bushel durum

Symbol:	**U_w**	Unit:	[kg / bushel]								
Durum model		Distribution	Para 1	Para 2	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Total	original	COSTANT(value)	27.22		27.22	0.00%	27.22	27.22	27.22	27.22	27.22
	updated	WEIBULL(,)	74.17	28.44	28.22	1.71%	26.72	27.32	28.30	28.86	29.03

Para = parameter; perc. = percentile.

Parameters of the wheat for flour sub-pathway

Probability bunted kernels exported to EU country $P_{part,i}$ *[-]*

The percentages of durum wheat exported to Italy in the years from 1995 to 2004 were calculated from FAOSTAT data. A Beta distribution was fitted to the yearly data by matching the first two moments. It is obvious that the original BETA distribution does not reflect the year by year variability.

Probability bunted durum kernels exported to EU country

Symbol:	**P_part_i**	Unit:	[-]								
Durum model		Distribution	Para 1	Para 2	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Italy	original	BETA(n, s)	2963	7664	38.66%	1.44%	37.37%	37.74%	38.66%	39.57%	39.96%
	updated	BETA(a_1, a_2)	2.168	3.617	37.48%	49.58%	4.42%	9.71%	35.95%	70.51%	81.75%

BETA (n,s): n=no. part (total metric tons exported to EU country), s= no. total (total metric tons US wheat exported); Para = parameter; perc. = percentile.

Probability exported wheat is a class grown in the US regulated areas $P_{class,i}$ *[-]*

The percentages of desert durum wheat in relation to total wheat export to Italy in the years from 1997 to 2007 were calculated from data obtained from Appendix 46/47 of the USDA APHIS document. A Beta distribution was fitted to the yearly data by matching the first two moments. Again the year by year variation was not reflected by the original model.

Probability exported durum is a class grown in the US regulated areas

Symbol:	**P_class_i**	Unit:	[-]								
Durum model		Distribution	Para 1	Para 2	mean	CV	1%-perc.	5%-perc.	median	95%-perc.	99%-perc.
Italy	original	BETA(n, s)	1799543	3324139	54.14%	0.05%	54.07%	54.09%	54.14%	54.18%	54.20%
	updated	BETA(a_1, a_2)	2.822	1.616	63.58%	32.45%	14.54%	26.31%	65.77%	93.36%	97.62%

BETA (n,s): n=no. part (total exported metric tons of wheat classes grown in US regulated areas), s= no. total (total metric tons exported wheat); Para = parameter; perc. = percentile.

2.2.7. Outputs of the updated USDA APHIS wheat and desert durum wheat grain models

2.2.7.1. Discussion of the outputs of the updated models

Wheat for grain

The probability distributions of number of teliospores per hectare computed with the updated model (10,000 Monte Carlo simulations) are described in Table 19 for the case of wheat for grain. The results show that the mean number of teliospores per hectare one year after import ranges from zero (Malta, Sweden) to 272 (Estonia). The mean numbers of teliospores per hectare were lower with the updated model (Table 19) than with the original model (Table 15). For example, the mean number of teliospores per hectare in Italy was equal to 154.09 with the original model, but was only equal to 130 with the updated model.

Table 19: Probability distributions of number of teliospores per ha computed with the updated wheat for grain model for each EU country. Teliospores on surface after 1st year per member state [1/(ha y)]

State	Mean	CV	1%	5%	50%	95%	99%
Austria	0.486	1892%	7.47E-09	1.11E-07	4.65E-04	0.864	7.15
Belgium-Luxembourg	127	1830%	2.83E-08	5.34E-07	0.0286	171	1828
Bulgaria	37.2	3533%	0	0	0	35.5	356

Cyprus	635	1525%	3.77E-07	7.57E-06	0.199	1011	10281
Czech Republic	0.224	2408%	3.85E-09	5.45E-08	3.10E-04	0.390	3.27
Denmark	1	1622%	0	0	0	1	10
Estonia	272	4914%	4.09E-09	6.08E-08	3.66E-04	44.2	1264
Finland	0.342	1743%	2.26E-09	2.17E-08	1.44E-05	0.101	3.45
France	0.523	2596%	0	0	0	0.234	7.47
Germany	4.87	1670%	9.52E-10	1.79E-08	3.31E-04	5.24	81.7
Greece	4.02	1117%	3.91E-09	6.23E-08	5.59E-04	5.10	69.16
Hungary	0.374	2209%	2.06E-09	2.21E-08	8.11E-05	0.360	5.49
Ireland	4.00	1585%	1.45E-08	2.64E-07	9.46E-04	4.78	53.1
Italy	130	2266%	3.97E-09	1.31E-07	0.0431	228	1919
Latvia	39.0	4067%	1.89E-08	3.70E-07	0.00580	38.0	425
Lithuania	14.9	5835%	8.65E-09	1.17E-07	9.88E-04	7.55	104
Malta	0	0%	0	0	0	0	0
Netherlands	123	1468%	2.41E-08	4.43E-07	0.0112	154	2067
Poland	4.12	2585%	0	0	0	0.692	30.4
Portugal	0.563	1671%	9.80E-10	1.03E-08	1.24E-05	0.184	7.58
Romania	30.3	1636%	0	0	0	19.80	470
Slovakia	0.0207	1457%	4.97E-09	4.97E-08	7.70E-05	0.0345	0.326
Slovenia	36.7	2973%	0	0	0	7.72	262
Spain	4.81	1783%	1.02E-09	1.79E-08	1.67E-04	2.83	57.9
Sweden	0	0%	0	0	0	0	0
United Kingdom	0.292	1944%	5.39E-11	8.76E-10	1.87E-06	0.0852	2.62

The coefficients of variation were higher with the updated model than with the original model for all countries other than Malta, and Sweden, where the simulated number of teliospores was systematically equal to zero. For the other countries, the coefficient of variation was more than ten times higher with the updated model. For example, for Italy, the coefficient of variation was equal to 2266 % with the updated model but was equal to 136 % with the original model. These results show that the uncertainty is very high due to both lack of knowledge about parameter values and between year variability of wheat production and positive ha. The consequence of this very high uncertainty is that low and high percentiles of the teliospore number distribution are very different from the mean values and the distribution is heavily skewed. For example, for Italy, the 5 % and 95 % percentiles were equal to 1.31 10^{-7} and 228 teliospores per ha respectively, and the 1 % and 99 % percentiles were equal to 3.97 10^{-9} and 1919 teliospores per ha respectively (median = 0.0431, mean value = 130).

As already noted for the original model, the simulated numbers of teliospores does not reflect the possible within-country spatial heterogeneity of teliospore density. Thus, for a given country, the number of teliospores per ha can be higher or lower than the values reported in table 19 depending on the spatial distribution of teliospores within the country.

Desert durum wheat for grain

With the updated model, the mean number of teliospores per ha in Italy one year after import was equal to 1998 per ha (Table 20), and so was lower than the mean number obtained with the original model (3094.4 per ha). The coefficient of variation derived from the updated model was equal to 803 % and, so, was much higher than the coefficient of variation derived from the original model (138 %). The level of uncertainty provided by the updated model was thus higher. The consequence of this result is that the 1 % and 99 % percentiles took more extreme values with the updated model than with the original model; with the original model the 1% and 99% percentiles were equal to 34.2 and 20116.6 teliospores per ha respectively, whereas with the updated model these percentiles were equal to 6.81 10^{-10} and 48809 teliospores per ha respectively. As noted in the case of wheat for grain, these values do not reflect the possible within-country spatial heterogeneity of the number of teliospores per ha.

Table 20: Probability distributions of number of teliospores per ha computed with the updated desert durum wheat for grain model for Italy. Teliospores on surface after 1st year [1/(ha y)]

Mean	CV	1%	25%	50%	95%	99%
1998	803%	6.81E-10	2.47E-08	0.261	5336	48809

2.2.7.2. Sensitivity analysis of the output to the inputs for the updated model

Wheat for grain

Table 21 shows the sensitivity indices derived from the 10,000 Monte Carlo simulations performed with the updated model for wheat for grain. The number of parameters with indices higher than 0.05 is equal to 13, and so is higher than the number obtained with the original wheat for grain model (7). As noted with the original wheat for grain model, the highest sensitivity index was obtained for the parameter “proportion of kernels that are bunted in regulated counties of Arizona” (index=0.237). The next 37 parameters were related to some EU member state characteristics: probability of exported wheat to EU member states is a class grown in regulated areas, probability of teliospores released during milling, probability of spilled teliospores, and probability of manure dispersed to wheat production area. These parameters had very low indices with the original wheat for grain model and this important difference is due to the fact that additional sources of variability of member state data were taken into account in the updated model. The other parameters with indices higher than 0.02 were “positive hectares in Arizona” (index=0.025), “proportion that are bunted kernels in California” (index=0.02) and “teliospores per bunted kernel” (index=0.02) have had also indices higher values than 0.02 with the original wheat for grain model. On the other hand, the indices of “proportion of teliospores on surface”, “proportion of teliospores that survive cattle digestion”, “probability feed lot manure used as fertilizer”, “proportion of bunted kernels escaping detection by PPQ in Arizona” were lower than 0.02 with the updated wheat for grain model although they were higher than 0.09 when computed with the original wheat for grain model. In summary the updated model shows a more homogeneous structure of uncertainty on all influencing factors.

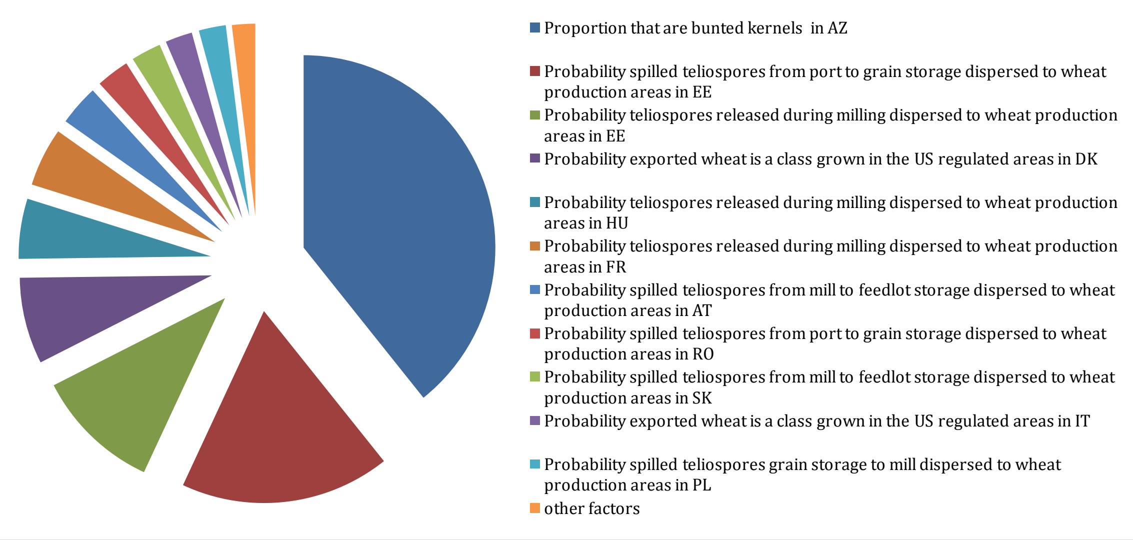
Table 21: Sensitivity indices, derived from the 10,000 Monte Carlo simulations performed with the updated model for wheat for grain, on average teliospores on surface after 1st year.

Name	State	Sensitivity
Proportion that are bunted kernels	Arizona	0.237
Probability spilled teliospores from port to grain storage dispersed to wheat production areas	Estonia	0.159
Probability teliospores released during milling dispersed to wheat production areas	Estonia	0.123
Probability exported wheat is a class grown in the US regulated areas	Denmark	0.102
Probability teliospores released during milling dispersed to wheat production areas	Hungary	0.085
Probability teliospores released during milling dispersed to wheat production areas	France	0.084
Probability spilled teliospores from mill to feedlot storage dispersed to wheat production areas	Austria	0.07
Probability spilled teliospores from port to grain storage dispersed to wheat production areas	Romania	-0.063
Probability spilled teliospores from mill to feedlot storage dispersed to wheat production areas	Slovakia	0.06

Probability exported wheat is a class grown in the US regulated areas	Italy	-0.057
Probability spilled teliospores grain storage to mill dispersed to wheat production areas	Poland	0.057
Probability manure dispersed to wheat production areas	France	0.053
Probability spilled teliospores grain storage to mill dispersed to wheat production areas	Estonia	-0.05
Probability exported wheat is a class grown in the US regulated areas	Estonia	-0.046
Probability exported wheat is a class grown in the US regulated areas	Lithuania	0.045
Probability manure dispersed to wheat production areas	Poland	0.045
Probability spilled teliospores from mill to feedlot storage dispersed to wheat production areas	Poland	-0.044
Probability exported wheat is a class grown in the US regulated areas	Slovakia	0.044
Probability spilled teliospores from mill to feedlot storage dispersed to wheat production areas	United Kingdom	-0.038
Probability spilled teliospores grain storage to mill dispersed to wheat production areas	Slovenia	0.037
Probability spilled teliospores from mill to feedlot storage dispersed to wheat production areas	Ireland	0.036
Probability exported wheat is a class grown in the US regulated areas	Bulgaria	-0.035
Probability manure dispersed to wheat production areas	Romania	0.034
Probability teliospores released during milling dispersed to wheat production areas	Austria	0.033
Probability teliospores released during milling dispersed to wheat production areas	Slovenia	-0.033
Probability exported wheat is a class grown in the US regulated areas	Belgium-Luxembourg	-0.032
Probability spilled teliospores from mill to feedlot storage dispersed to wheat production areas	Finland	0.032
Probability exported wheat is a class grown in the US regulated areas	Austria	-0.029
Positive hectares	Arizona	0.025
Probability exported wheat is a class grown in the US regulated areas	Spain	-0.025
Probability spilled teliospores grain storage to mill dispersed to wheat production areas	United Kingdom	0.025
Probability spilled teliospores grain storage to mill dispersed to wheat production areas	France	0.024
Probability exported wheat is a class grown in the US regulated areas	Latvia	-0.024
Probability spilled teliospores from mill to feedlot storage dispersed to wheat production areas	Romania	0.023
Probability teliospores released during milling dispersed to wheat production areas	Finland	-0.022
Probability spilled teliospores from mill to feedlot storage dispersed to wheat production areas	Spain	0.022
Probability teliospores released during milling dispersed to wheat production areas	Slovakia	0.021
Probability manure dispersed to wheat production areas	Slovenia	-0.021
Proportion that are bunted kernels	California	0.02
Teliospores per bunted kernel	Total	0.02
Probability exported wheat is a class grown in the US regulated areas	Finland	-0.02
Probability spilled teliospores from port to grain storage dispersed to wheat production areas	Poland	-0.02
Probability spilled teliospores from mill to feedlot storage dispersed to wheat production areas	Portugal	-0.017
Probability exported wheat is a class grown in the US regulated areas	Czech Republic	-0.016

Probability teliospores released during milling dispersed to wheat production areas	Poland	0.016
Probability spilled teliospores from port to grain storage dispersed to wheat production areas	Portugal	-0.016
Proportion of teliospores on surface	Total	0.015
Probability exported wheat is a class grown in the US regulated areas	France	0.015
Probability spilled teliospores grain storage to mill dispersed to wheat production areas	Romania	-0.015
Probability teliospores released during milling dispersed to wheat production areas	Portugal	-0.014
Probability exported wheat is a class grown in the US regulated areas	Germany	-0.012
Probability spilled teliospores grain storage to mill dispersed to wheat production areas	Cyprus	-0.011
Probability spilled teliospores from mill to feedlot storage dispersed to wheat production areas	Estonia	0.011
Proportion teliospores that survive cattle digestion	Total	0.01
Probability spilled teliospores grain storage to mill dispersed to wheat production areas	Austria	0.01
Probability exported wheat is a class grown in the US regulated areas	Greece	-0.01
Probability exported wheat is a class grown in the US regulated areas	Ireland	0.009
Probability teliospores released during milling dispersed to wheat production areas	Romania	-0.009
Probability exported wheat is a class grown in the US regulated areas	Poland	0.008
Probability exported wheat is a class grown in the US regulated areas	United Kingdom	0.008
Proportion that are bunted kernels	Texas	0.007
Probability spilled teliospores grain storage to mill dispersed to wheat production areas	Finland	-0.007
Probability spilled teliospores from port to grain storage dispersed to wheat production areas	France	-0.007
Probability spilled teliospores from feedlot storage to feedlot dispersed to wheat production areas	Italy	0.007
Probability exported wheat is a class grown in the US regulated areas	Portugal	-0.007
Probability exported wheat is a class grown in the US regulated areas	Slovenia	-0.007
Probability spilled teliospores from mill to feedlot storage dispersed to wheat production areas	France	-0.006

Standardized Regression Coefficients (b), $R^2=0.617$
Variables with b>=0.005 included



Legend: Plotted are the proportions of the squared sensitivity indices to the total R^2 value, which can be interpreted as importance of the influence factor on the overall variation / uncertainty.

Figure 5: Importance of the influence variables in the updated model for wheat for grain, on average teliospores on surface after 1st year

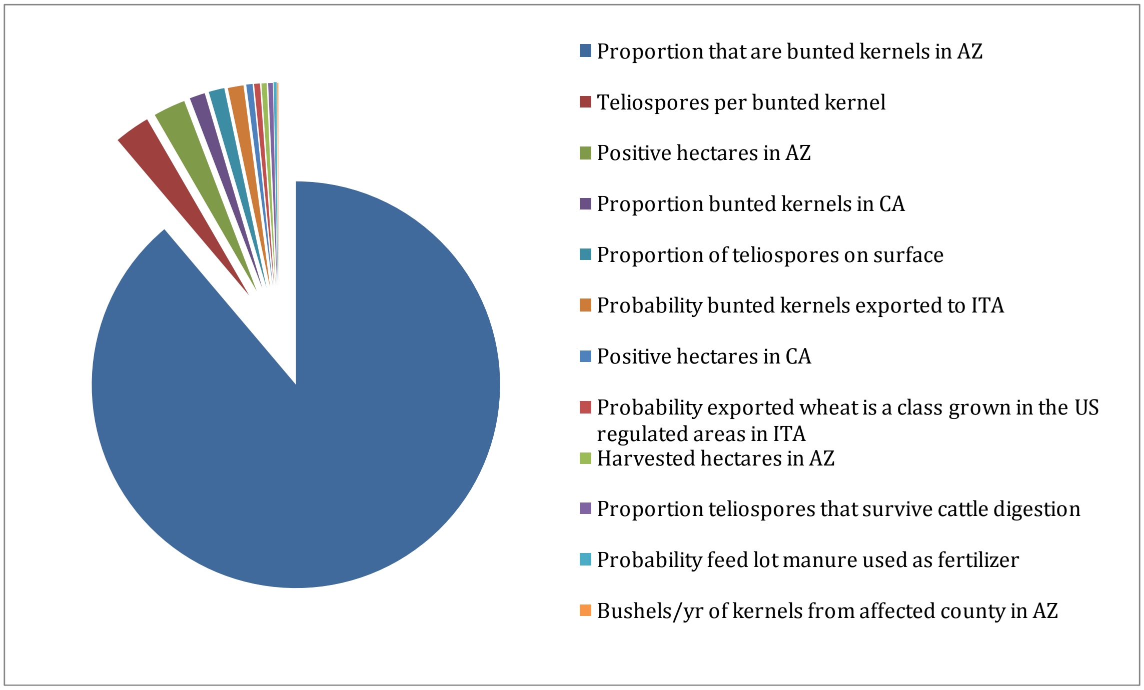
Desert durum wheat for grain

Table 22 shows the sensitivity indices derived from the 10,000 Monte Carlo simulations performed with the updated model for durum wheat. These indices indicate the influence of each parameter on the number of teliospores on the surface in Italy.

Table 22: Sensitivity indices, derived from the 10,000 Monte Carlo simulations performed with updated model for desert durum wheat, on average teliospores on surface after 1st year.

Name	State	Sensitivity
Proportion that are bunted kernels	Arizona	0.466
Teliospores per bunted kernel	Total US	0.083
Positive hectares	Arizona	0.079
Proportion that are bunted kernels	California	0.055
Proportion of teliospores on surface	Total US	0.055
Probability bunted kernels exported to EU country	Italy	0.055
Positive hectares	California	0.035
Probability exported wheat is a class grown in the US regulated areas	Italy	0.034
Harvested hectares	Arizona	-0.032
Proportion teliospores that survive cattle digestion	Total US	0.030
Probability feed lot manure used as fertilizer	Total US	0.024
Bushels/yr of kernels from affected county	Arizona	0.015

Standardized Regression Coefficients (b), R^2=0.304
Variables with b>=0.01 included



Legend: Plotted are the proportions of the squared sensitivity indices to the total R^2 value, which can be interpreted as importance of the influence factor on the overall variation / uncertainty.

Figure 6: Importance of the influence variables in the updated model for desert durum wheat, on average teliospores on surface after 1st year

Sensitivity indices were higher than 0.05 for six parameters, namely: proportion of kernels that are bunted in regulated counties of Arizona (index=0.466), teliospores per bunted kernel (index=0.083), positive ha in Arizona (index=0.079), proportion of teliospores on surface (index=0.055), probability of bunted kernels exported to Italy (index=0.055), proportion of kernels that are bunted in regulated counties of California (index=0.055). Overall, the indices obtained with the updated durum wheat model were close to the indices obtained with original durum wheat model. The main differences were:

- The indices obtained with the updated durum wheat model for the parameters “probability feed lot manure used as fertilizer”, “proportion of bunted kernels escaping detection by PPQ in Arizona”, and “proportion of teliospores that survive cattle digestion” were lower or equal 0.03 although they were higher than 0.05 with the original model.

- The indices obtained with the updated durum wheat model for the parameters “probability of bunted kernels exported to Italy” and “proportion of kernels that are bunted in regulated counties of California” were higher than 0.05, but were lower than this value when computed with the original durum wheat model.

Here also, the differences between the original and updated durum wheat models can be explained by the additional sources of variability of the member states data considered in the updated model. The parameter “proportion of kernels that are bunted in regulated counties of Arizona” (index=0.466) remains a distinct source of uncertainty in the original and updated wheat and durum models.

2.3. Conclusions on the USDA APHIS quantitative pathway analysis

2.3.1. Model structure and parameter values

The USDA APHIS model was reviewed by the Panel and several shortcomings were found with respect to the model equations and parameter values.

- Entry of *T. indica* in Europe is considered to be uniform within a country. A mean value of teliospores on the soil surface is computed per hectare of wheat production. No consideration is given to spatial aggregation of teliospores, in which some areas have values much higher and other areas much lower than the mean (Allen et al., 2008; Sawyer et al., 1997).

- The pathway analysis does take into account overwintering survival of teliospores which may add to the pool of teliospores the next season, but does not take into account teliospores produced *in situ* through the infection process above and which may subsequently be air-dispersed.

- The pathway analysis does not consider the possibility that a single infected consignment could reach a specific location in Europe.

- The pathway analysis assumes that 150000 teliospores on the soil surface per hectare are required for introduction. This is based on a supposed inoculum threshold of 15 teliospores/m^2 for 1 bunted kernel/m^2 which they then scale up by the factor 10^5 to give a threshold per hectare.

- There is no evidence for the existence of an infection threshold. . The value given is based on a misunderstanding of a theoretical paper (Murray and Sansford, 2005). There are no experimental data which support the existence of an infection threshold (Murray and Brennan, 1998; Rush et al., 2005). One teliospore on germination can produce more than hundred primary sporidia (see Section 1.2), which in turn produce secondary sporidia which infect the plant. Both mating types are produced from a single teliospore (Durán and Cromarty, 1977) and hence new teliospores can be formed resulting in bunted kernels.

- Inaccurate estimation of several parameters of the model.

2.3.2. Model outputs

Two series of simulations were analyzed by the Panel:

i) Simulations computed with the original USDA APHIS model,

ii) Simulations computed with an updated version of the model based on the same equations but with parameter values modified according to the available literature and data.

Both models were used to compute the number of teliospores per hectare on the soil surface of each country of the EU. In both models, it was assumed that the US bunted kernel standard was implemented to detect the presence of the disease in wheat grains produced in regulated counties.

Simulated numbers of teliospores entering into the EU were lower with the updated version of the model than with the original version. However, both modified models showed that teliospores from *T. indica* can enter into EU and, consequently, that the US bunted kernel standard cannot be used alone to certify that grains exported from regulated counties is free from *T. indica*.

Our results showed that there is a high uncertainty about the exact number of teliospores entering in each country in EU and about the possibility of infection of European wheat from these teliospores due to lack of knowledge about key parameters and between year variability of wheat production and positive ha in regulated counties. The uncertainty was underestimated with the original model.

The sensitivity analysis carried out by the Panel showed that several key parameters strongly influence the simulated number of teliospores entering into the EU. With all the four tested models, the most influential parameter was the proportion of kernels that are bunted in regulated counties of Arizona. The number of positive hectares in Arizona and the number of teliospores per bunted kernel were also systematically found among the parameters with the highest sensitivity indices. In addition to these three parameters, high sensitivity indices were obtained with the wheat for grain updated model for several parameters related to EU member state characteristics (probabilities of spilled teliospores being dispersed to wheat production areas, probability of teliospores released during milling being dispersed to wheat production areas, probability that wheat exported to EU member states is in a class grown in the US regulated areas, probability of manure being dispersed to wheat production area). Further research is needed to refine these parameter values and reduce the uncertainty about the simulated number of teliospores entering the EU. Further research is also needed to determine the relationship between teliospores number on the soil surface and the number of bunted kernels that result from infection of a wheat plant.

2.3.3. USDA APHIS quantitative pathway analysis conclusion

The USDA APHIS claims that the probabilistic quantitative pathway analysis indicates that “the US bunted kernel standard adequately prevents the export of epidemiological significant levels of *T. indica* in US grain“.

This claim cannot be substantiated for the following reasons:

- Epidemiological significance can only be judged in terms of the introduction potential of the organism into the EU territories.
- The quantitative pathway analysis (the original model and the updated versions considered in this opinion) predicts that teliospores enter the EU territories via the grain for consumption pathway.
- The numbers of teliospores on the soil surface can be converted to bunted kernels per hectare (using the USDA APHIS threshold assumption) but the numbers obtained would be very small in relation to the number of kernels produced per hectare of wheat. This would place major sampling constraints on observing the disease in the field.
- Introduction depends on entry and establishment. The quantitative pathway analysis predicts that entry will occur but cannot be used to predict whether the organism will establish.

Therefore whether introduction is epidemiologically non-significant or not cannot be judged from the quantitative pathway analysis alone. More sophisticated epidemiological data collection and analysis would be required to make this judgement.

3. Level of protection provided by the US bunted kernel standard and the EU requirements

3.1. Introduction

This part of the opinion reviews the literature on diagnosis of Karnal bunt disease and detection of the pathogen, *T. indica*. Furthermore, the level of protection provided by the US bunted kernel standard is compared with that of the EU requirements.

3.2. Diagnosis of Karnal bunt

Karnal bunt is a disease of wheat florets with symptoms becoming evident only when the kernels are fully developed (dough stage) (Joshi et al., 1983; Nagarajan, 2001). As a result, the symptoms of the disease are unlikely to be detected in the field before the crop is near maturity (Bonde et al., 1997; Ottman, 2002). However, even then, the symptomatic kernels are difficult to detect unless the grain is threshed and examined (Forster and Goates, 1997). This is mainly due to the aggregation of infected plants in a wheat field, the irregular distribution of symptomatic kernels in a spike (Mundkur, 1940; Joshi et al., 1983). Not all the spikes of a plant show symptoms of the disease, and within a spike only a few kernels may be bunted (Fuentes-Dávila, 1997; Rattan and Aujla, 1991; Bonde et al., 1997; Babadoost, 2000). The disease severity on individual kernels varies from small points of infection (tip-infected kernels) to completely bunted kernels (Bedi et al., 1949; Joshi et al., 1983; Mitra, 1931) with most of the infected kernels being partially bunted (partial bunt). Only in severely infected spikelets do the glumes spread apart near maturity, exposing the bunted kernels, but this is not a common symptom (Bedi et al., 1949; Chona et al., 1961; Joshi et al., 1983; Mitra, 1931). In addition, Karnal bunt symptoms are unlikely to be detected in the field, as the disease incidence is usually very low (Babadoost, 2000; Murray and Brennan, 1998; Rush et al., 2005). The above observations are further supported by the information provided in the USDA APHIS Karnal bunt manual (2007) and the USDA APHIS Karnal bunt survey (2009) according to which the grain samples intended for testing for the presence/absence of the disease are collected from the combine during harvest or from the elevators after harvest, respectively. Nevertheless, three other fungal diseases of wheat, namely black point (*Alternaria alternata*), common bunt (*Tilletia tritici*, *Tilletia laevis*) and dwarf bunt (*T. controversa*) develop similar symptoms and they can thus be mistaken for Karnal bunt (Forster and Goates, 1997). Therefore, the disease is difficult to detect under field conditions without laboratory tests (Babadoost, 2000; Bonde et al., 1997).

Two laboratory methods for the detection of symptomatic kernels (bunted kernels) in grain samples collected at harvest are described in the “bunted kernel standard” protocol (USDA APHIS Karnal bunt manual, 2007): the first one, used in Olney, Texas, is based on a high-speed optical sorter developed by Dowell et al. (2002) and the second one, used in the other States, is based on visual examination of grain by trained personnel.

In the first method and according to Dowell et al. (2002), when a grain sample with a known number of bunted kernels was used, the high-speed optical sorter removed all bunted kernels when 8 % or more of the sample was rejected, whereas a two-pass sort increased the chance of removing all bunted kernels at lower rejection rate. At a confidence limit of 95 % and assuming a binomial distribution, the minimum likely true proportion of bunted kernels that are expected to be recovered at this rejection rate was about 99.0 % (Dowell et al., 2002). When 0.2 % of the sample was rejected, more than 70 % of the bunted kernels were contained in the rejected portion. Dowell et al. (2002) also reported that bunted kernels with the tip and canoe type of infection are more likely to escape detection than other types of bunted kernels, as in those cases the area of infection only slightly exceeds the resolution of the optical sorter (Dowell et al., 2002). However, Dowel et al. (2002) also suggested that the sorter settings should be optimised for other wheat classes and cultivars.

In the second method, where the detection of bunted kernels is done by visual inspection of the grain samples, Dowell et al. (2002) mentioned that, according to unpublished studies conducted by USDA

APHIS, experienced personnel recovered only 77 % of bunted kernels from 30 samples containing from 3 to 10 bunted kernels, possibly because some infected kernels (bunted kernels) may be missed either when the infected portion of the kernel is not oriented toward the inspector or due to inspector fatigue (Dowell et al., 2002). Aggarwal and Verma (1983) also stated that direct visual observation of kernels for Karnal bunt symptoms is regarded as insufficient since low levels of kernel infection or kernels covered by dust might go undetected. Moreover, as mentioned above, symptoms caused on wheat kernels by other fungal pathogens (*Alternaria alternata*, *T. controversa*, *T. tritici*, etc.) could be mistaken for Karnal bunt.

Therefore, a reliable diagnosis of Karnal bunt disease should be based on the detection and further characterisation of the pathogen's teliospores produced in sori on the infected kernels (bunted kernels). However, even then, it is imperative that suspect wheat samples be assessed by experts (DPHQ, 2001).

3.3. Detection of *T. indica* teliospores

Tilletia species have been described, and therefore may be distinguished, based on the morphology of their teliospores (size, type of ornamentation, colour, etc.) (Castlebury et al., 2005). Nevertheless, as the teliospores of some other *Tilletia* species commonly found in harvested grain [i.e., *T. walkeri* (ryegrass bunt), *T. horrida* (rice bunt) and *T. ehrhartae* (perennial veldt grass smut)] are similar in morphology with those of *T. indica*, they can be confused with those of the pathogen, particularly when only a few teliospores are detected (Inman et al., 2003). *T. walkeri* and *T. ehrhartae* are present in Australia and are found to contaminate harvested wheat grain (Wright et al., 2003). *T. walkeri* and *T. horrida* are present in the US and in Asia and are detected in harvested grain, especially where rice and ryegrass are grown in rotation with wheat (Pascoe et al., 2005; Castlebury and Carris, 1999; Castlebury, 1998). Detection methods in use for *T. indica* teliospores take into account these difficulties in diagnosis and, depending on the number of teliospores detected, may combine morphologically-based and biomolecular identification methods (Bonde et al., 1989; Ferreira et al., 1996; Frederick et al., 2000; Inman et al., 2003; Levy et al., 2001; McDonald et al., 2000; Peterson et al., 2000; Smith et al., 1996; Tan and Murray, 2006; Tan et al., 2009).

For the detection of teliospores of *T. indica* in infested grain or seed samples, a size-sieve selective method was developed by Peterson et al. (2000). According to this method, a 50 g grain sample is washed through 53-μm and 20-μm pore size nylon screens to remove unwanted debris and to concentrate and isolate teliospores. The material retained in the 20-μm screen is suspended for direct microscopic examination or plated on water agar for teliospore germination and subsequent identification by polymerase chain reaction (PCR) utilizing two pairs of T. indica–specific primers. The reliability of detection for both light microscopy and PCR was 100 % at an infestation level of five teliospores per 50 g sample. The proportion of teliospores recovered from grain samples artificially infested (spiked) with *T. indica* teliospores was 0, 82, 88, 81, and 82 %, respectively, at infestation levels of 0, 1, 2, 5, and 10 teliospores per 50-g wheat sample. For the detection of 1 to 2 teliospores per 50 g of wheat, the sensitivity of the method was much higher than that of the PCR method. Inman et al. (2003) estimated that, using this method, three replicate sub-samples of 50 g each are required to detect one teliospore of *T. indica* at the 99 % level of confidence. When five teliospores are present in the sub-sample, one single 50 g sample is sufficient for the detection of *T. indica* teliospores at a 99.9 % level of confidence. The current EPPO standard for the detection and identification of *T. indica* (EPPO, 2004) applies the size-selective sieving method, developed by Peterson et al. (2000). This method is also used by the USDA APHIS for the detection of *T. indica* teliospores on wheat seed samples and for distinguishing the pathogen from *T. walkeri* or other smut fungi (USDA APHIS Karnal bunt manual, 2007).

Sánchez-Ramírez (1994) reported that by combining washing and filtering through filter-paper or polyester membranes, even three *T. indica* teliospores on 1 million of kernels could be detected, with a recovery efficiency of 90 % of the teliospores present in the sample.

Various molecular methods have also been developed for the detection of *T. indica* teliospores on infested grain or seed samples (Frederick et al., 2000; Levy et al., 2001; Wright et al., 2003).

Nevertheless, most of these methods require the germination of teliospores in order to provide the template DNA for further analysis. However, germination of *T. indica telio*spores takes at least two weeks (Castlebury and Carris, 1999) and may not occur because of dormancy, etc. In order to bypass the germination step, Tan et al. (2009) have recently developed a molecular assay with increased specificity and sensitivity. The protocol involves the release of DNA from teliospores, PCR amplification to enrich *Tilletia*-specific templates from released DNA and a five-plex, real-time PCR assay to detect, identify and distinguish *T. indica* from other *Tilletia* species (*T. walkeri*, *T. ehrhartae*, *T. horrida*, and a group comprising *T. caries*, *T. laevis*, *T. controversa*, *T. bromi* and *T. fusca*) in wheat grains. This fluorescent molecular tool, consisting first of an amplification step to enrich *Tilletia*-specific DNA (Tan and Murray, 2006) from a single teliospore or a low concentration of *Tilletia*-specific DNA in a total DNA extract, has a detection sensitivity of one teliospore and bypasses the germination step, which in the current protocols is required for confirmation when only a few teliospores are detected in infested grain samples. The assay contains five dual-labelled, species-specific probes and associated species-specific primer pairs in a PCR mix in one tube. The different amplification products are detected simultaneously by five different fluorescence spectra. This specific and sensitive assay with reduced labour and reagent requirements is a promising tool to be used in Karnal bunt surveillance programmes.

3.4. Description of the EU requirements and the US bunted kernel standard

The Council Directive 2000/29/EC includes protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community. Paragraph 54 of Annex IV Part A Section I of the Directive describes special requirements which must be laid down by all EU Member States, for the introduction and movement of grain of the genera *Triticum*, *Secale* and × *Triticosecale* from Afghanistan, India, Iraq, Mexico, Nepal, Pakistan and the US, where *T. indica* is known to occur.

The EU requirements are included in Table 23 together with a summary of the sampling and testing procedures (US bunted kernel standard) applied by the US to grain produced in regulated and non-regulated areas and which procedures are described in detail in the USDA APHIS Karnal bunt manual (2007) and the USDA APHIS national Karnal bunt survey plan (2009), respectively.

The EU requirements (Table 23) aim at preventing the entry of the pathogen *T. indica* into the EU territory by importing wheat grain originating either in an area where *T. indica* is known not to occur or in a place of production in which the plants had been found free from disease symptoms during the last complete cycle of vegetation **and** the grain had been tested twice, both at harvest and before shipment, and found free from *T. indica*.

The Panel reviewed both the USDA APHIS documents (i.e., USDA APHIS Karnal bunt manual, 2007 and USDA APHIS national Karnal bunt survey, 2009) and found that the US has adopted different sets of measures to deal with Karnal bunt in the wheat-producing States depending on (i) the areas where Karnal bunt is known to occur or not (regulated and non-regulated areas), and (ii) the end-use of the wheat produced, i.e., for sowing (seed) or consumption (grain).

More specifically, the USDA APHIS Karnal bunt manual (2007) describes the guidelines and regulation actions for the production, handling and transportation of wheat grain (and seed) produced in infested areas (regulated areas). In the areas of US wheat-producing States where the disease has not previously been detected (in States where Karnal bunt has never been detected and outside the regulated areas within States where Karnal bunt has been detected[7]), a national Karnal bunt survey is conducted, with the purpose (i) to provide US certifying officials the ability to issue phytosanitary certificates and additional declaration if required by the countries where the US exports wheat, and (ii) to establish Karnal bunt pest-free areas in the US (USDA APHIS national Karnal bunt survey, 2009).

---

[7] As per clarifications kindly provided in e-mail of 12 April 2010 by G. Galasso, National Trade Director, Grain Programs, PPQ APHIS USDA to G. Cardon, DG SANCO, European Commission.

Table 23: Comparison of EU requirements for grain of the genera *Triticum*, *Secale* and *xTriticosecale* and the sampling and testing procedures (bunted kernel standard) described in the USDA APHIS Karnal bunt manual (2007) and the USDA APHIS national Karnal bunt survey (2009).

EU requirements (Council Directive 2000/29/EC Annex IV, Part A, Section I, paragraph 54)	**USDA APHIS Karnal bunt manual (2007)**[2]	**USDA APHIS national Karnal bunt survey (2009)**[3]
Official statement that:		
EITHER The grain originates in an area where *Tilletia indica* Mitra is known not to occur. The name and of the area or areas shall be mentioned on the phytosanitary certificate provided for in Article 7, under the rubric "place of origin"		
OR No symptoms of *Tilletia indica* Mitra have been observed on the plants at the place of production during their last complete cycle of vegetation	Crops from fields previously tested positive for bunted kernels are not eligible for export to countries that require an Additional Declaration (see footnote 2 of Table 3-3: Grain from Karnal Bunt Regulated areas)	
AND representatives samples of the grain have been taken	Sampling method A 4-pound (i.e. 1.82 kg) grain sample is taken from a combine containing 1,000 pounds of grain	Sampling method A 4-pound sample is taken for every 1,000,000 bushels of production (1 bushel = 0.035 m^3) plus an additional 250 g sample, which is retained by the State as a reference sample
BOTH At the time of harvest **AND** Before shipment	Sampling timing Prior to harvest (no further details are provided) ***OR*** At the time of harvest	Sampling timing After harvest from local elevators located in Karnal bunt free areas (from one or several elevators per county according to production) **OR** from storage or transfer bins at county elevators, although it is not a preferred alternative.

AND have been tested and found free of *Tilletia indica* Mitra in these tests; the latter shall be mentioned on the phytosanitary certificate provided for in Article 7, in the rubric "name of produce" as "tested and found free from *Tilletia indica* Mitra"	Testing method Grain samples are sent to the nearest lab/bunted kernel machine and are tested for the presence/absence of bunted kernels using one of the following methods: High speed optical sorter (available in Olney, Texas) Grain inspection machine Manual method Suspect bunted kernels must be examined for the presence of *T. indica* teliospores, and the presence of *T. indica* must be verified by an identifier with identification authority	Testing method Grain samples are sent to the USDA APHIS Karnal Bunt approved laboratories. The standard used for sample analysis is the bunted kernel one. Method of detection Survey samples submitted to Olney, Texas are tested by using a high speed optical sorter. All suspect kernels are then visually examined by trained personnel. In other States samples are tested for bunted kernels either by using a grain inspection machine or a visual examination by trained personnel In case suspect positive samples are detected, a bunted kernel specimen and a microscope slide with teliospores are sent to USDA-APHIS-PPQ National Identification Services (NIS) for confirmation.

1 *Secale cereale* (rye) is no longer considered to be a natural host of *T. indica* (Sansford et al., 2007)
2 Applied in US regulated areas
3 Conducted in wheat-producing States in areas where Karnal bunt has not been previously detected.

According to the USDA APHIS national Karnal bunt survey (2009), in 2009 the survey was performed on wheat (*Triticum aestivum*), durum wheat (*Triticum durum*) and triticale (*T. aestivum* × *Secale cereale*) grown in counties not sampled during the 2008 harvest year and where Karnal bunt had not been previously detected.

Table 23 shows the two basic differences between the EU requirements (Council Directive 2000/29/EC) and the US bunted kernel standard procedure described in the two USDA APHIS documents mentioned above:

- The EU requirements refer to two (2) dates of grain sampling and testing, i.e. at harvest and before shipment, while the US bunted kernel standard procedure includes only the first date of sampling and testing (i.e. at harvest).

- The EU requires the grain to be found free of *T. indica*, while the US bunted kernel standard procedure aims at detecting the presence of disease symptoms in the grain samples and not the presence of *T. indica* teliospores, which is the stage of the life cycle of the organism present on the wheat grain/seed pathway either as sori on infected kernels (bunted kernels) or as contaminants adherent to the surface of the kernels, even of healthy ones.

In the US bunted kernel standard procedure, teliospores are considered only for confirmation of the symptom-based diagnosis of the disease, as other wheat fungal diseases cause similar symptoms (see

3.2.). For the US regulated areas, suspect bunted kernels must be examined for the presence of *T. indica* teliospores (Table 23) whose morphological characteristics must be verified using a compound microscope, and the presence of *T. indica* must be verified by an identifier with identification authority (Karnal bunt manual, 2007, D-10). During the national Karnal bunt survey (USDA APHIS national Karnal bunt survey, 2009), when a suspect positive sample is detected by the Olney, Texas or a USDA APHIS approved Karnal bunt laboratory, a specimen and a microscopic slide must be sent to the USDA-APHIS-PPQ National Identification Services (NIS) for confirmation.

Based on the literature, freshly harvested healthy grain can be contaminated with teliospores of *T. indica* during harvesting, threshing and handling (Joshi et al., 1983; Nagarajan, 2001; Murray and Brennan, 1998). Moreover, each diseased kernel (bunted kernel) can produce thousands to millions of teliospores (Goates, 2008; Rattan and Aujla, 1990), which can contaminate farm machinery, the means of grain transportation (vehicles, railcars, etc) and storage facilities (elevators, bins, etc) (Bonde et al., 1997; Forster and Goates, 1997). Healthy grain can also become contaminated by passing through such equipment or facilities.

Based on the above, the Panel considers that the diagnostic methods described in the two above-mentioned USDA APHIS documents are not able to detect teliospores of *T. indica* present as contaminants on the grain surface. Moreover, kernels with tip (small sori located at the kernel tip, i.e. type 1 sori *sensu* Nagarajan 2001) or canoe type of infection are more subject to escape detection with the bunted kernel standard (Dowell et al., 2002). Therefore, the use of the US bunted kernel standard procedure (as decribed in USDA APHIS Karnal bunt manual, 2007) is inappropriate to certify that the grains are free from *T. indica*, because the presence of teliospores may not be excluded in samples characterised as negative through this procedure.

Therefore, the level of protection assured by the present EU requirements which take into account the detection of *T. indica* spores in addition to the bunted kernel standard is higher compared to the level of protection provided by the bunted kernel standard alone. A level of protection compared to the present level may only be warranted by measures which include testing at harvest and before shipment to detect teliospores infecting and contaminating grain imported into the EU.

3.5. Conclusion on the level of protection provided by the US bunted kernel standard and by the existing EU requirements

For grain consignments from countries where Karnal bunt is known to occur, the EU requires that grain samples are taken at two different times (at harvest and before shipment). However, in the US bunted kernel standard (USDA APHIS Karnal bunt manual, 2007) applied to regulated areas only, one time of sampling, either prior to or at harvest, is considered. In the USDA APHIS national Karnal bunt survey, (2009) applied to areas (i) where Karnal bunt has never been detected and (ii) outside the regulated areas within States where the disease has been detected, a different time of sampling (i.e. after harvest, at local elevators) is considered. Neither of the USDA APHIS documents include two sampling times nor consider sampling before shipment.

The EU requires the absence of the organism, whereas both the USDA APHIS documents (USDA APHIS Karnal bunt manual, 2007; USDA APHIS national Karnal bunt survey, 2009), concern the absence of disease symptoms on grain. Teliospores are considered only to confirm the suspect positive grain samples detected during the testing (using the optical sorter or visual examination).

The US bunted kernel standard does not provide an equivalent level of protection to the EU requirements for the following reasons:

- The EU requires absence of the organism on grain, while the US bunted kernel standard tests for disease symptoms on grain (i.e. for bunted kernels). The presence of teliospores in the US bunted kernel standard is tested only on the suspect bunted kernels in order to confirm the identification of the pathogen.

- The results of the simulations show that, by applying the US bunted kernel standard, teliospores may enter the EU with grain import.

- The US bunted kernel standard can detect diseased grain (bunted kernels) but not healthy grain carrying on its surface teliospores of the organism as contaminants.

- The US bunted kernel standard includes only one time of sampling and testing, at harvest, whereas the EU regulations require one additional sampling and testing to be made before shipment.

Therefore, a level of protection comparable to the present EU requirement can only be warranted by measures which include testing at harvest and before shipment to detect teliospores both infecting and contaminating grain imported into the EU.

4. Conclusions

With regard to the scientific opinion on the USDA APHIS quantitative pathway analysis, the Panel followed a tiered approach, reviewing the pathway scenarios, the model and the parameters. Results of simulations and sensitivity analysis were also analysed by the Panel for both the importation of US wheat for grain into the EU and desert durum wheat for grain into Italy. The Panel found several shortcomings with respect to the model equations and parameter values:

- the entry of *T. indica* in Europe was considered by USDA APHIS to be uniform within a country. A mean value of teliospores on the soil surface was computed per hectare of wheat production. No consideration was given to literature on spatial aggregation of teliospores, in which some areas show values much higher and other areas much lower than the mean.

- the pathway analysis took into account overwintering survival of teliospores, which might add to the pool of teliospores the next season, but did not take into account teliospores produced *in situ* through the infection process and which might subsequently be air-dispersed.

- the pathway analysis did not consider the possibility that a single infected consignment could reach a specific location in Europe.

- the pathway analysis assumed that 150000 teliospores on the soil surface per hectare were required for introduction. This was based on a supposed inoculum threshold of 15 teliospores/m^2 for 1 bunted kernel/m^2 which was then scaled up by the factor 10^5 to give a threshold per hectare.

- there is no evidence for the existence of an infection threshold. The value given was based on a misunderstanding of a theoretical paper. There are no experimental data which support the existence of an infection threshold. One teliospore on germination can produce more than one hundred primary sporidia, which in turn produce secondary sporidia which infect the plant. Both mating types are produced from a single teliospore and hence new teliospores can be formed resulting in bunted kernels.

- several parameters of the model were inaccurately estimated.

The Panel analyzed two series of simulations:

i) simulations computed with the original USDA APHIS model for both the importation of US wheat for grain into the EU and the importation of desert durum wheat for grain into Italy,

ii) simulations computed with an updated version of the model based on the same equations but with parameter values modified according to the available literature and data.

These simulations were run for both the importation of US wheat for grain into the EU and the importation of desert durum wheat for grain into Italy. Both models were used to compute the number of teliospores per hectare on the soil surface of each country of the EU. In both models, it was assumed that the US bunted kernel standard was implemented to detect the presence of the disease in wheat grains produced in regulated counties. Simulated numbers of teliospores entering the EU were lower with the updated version of the model than with the original version. However, both models showed that teliospores from *T. indica* could enter the EU and, consequently, that the US bunted kernel standard cannot be used alone to certify that grains exported from regulated counties are free from *T. indica*. These results showed that there is high uncertainty about the exact number of teliospores entering in each EU country and about the possibility of infection of European wheat from these teliospores due to lack of knowledge about key parameters and between year variability of wheat production and positive hectares in regulated counties. The uncertainty was underestimated with the original model.

The sensitivity analysis carried out by the Panel showed that several key parameters strongly influence the simulated number of teliospores entering into the EU. With all the four tested models, the most influential parameter was the proportion of kernels that are bunted in regulated counties of Arizona. The number of positive hectares in Arizona and the number of teliospores per bunted kernel were also systematically found among the parameters with the highest sensitivity indices. In addition to these three parameters, high sensitivity indices were obtained with the wheat for grain updated model for several parameters related to EU member state characteristics (probabilities of spilled teliospores being dispersed to wheat production areas, probability of teliospores released during milling being dispersed to wheat production areas, probability that wheat exported to EU member states is in a class grown in the US regulated areas, probability of manure being dispersed to wheat production area). Further research is needed to refine these parameter values and reduce the uncertainty about the simulated number of teliospores entering the EU. Further research is also needed to determine the relationship between teliospores number on the soil surface and the number of bunted kernels that result from infection of a wheat plant.

The USDA APHIS claimed that the probabilistic quantitative pathway analysis indicates that “the US bunted kernel standard adequately prevents the export of epidemiological significant levels of *T. indica* in US grain”. The Panel concluded that this claim could not be substantiated for the following reasons:

- epidemiological significance can only be judged in terms of the introduction potential of the organism into the EU territories.

- the quantitative pathway analysis (the original model and the updated versions considered in this opinion) predicted that teliospores enter the EU territories via the grain for consumption pathway.

- the numbers of teliospores on the soil surface could be converted to bunted kernels per hectare (using the USDA APHIS threshold assumption) but the numbers obtained would be very small in relation to the number of kernels produced per hectare of wheat. This would place major sampling constraints on observing the disease in the field.

- introduction depends on entry and establishment. The quantitative pathway analysis predicted that entry would occur but cannot be used to predict whether the organism will establish.

Therefore whether introduction is epidemiologically non-significant or is not could not be judged from the quantitative pathway analysis alone. More sophisticated epidemiological data collection and analysis would be required to make this judgement.

With regard to whether or not the US bunted kernel standard would provide an equivalent protection against the introduction of *T. indica* into the EU, compared to the existing EU import requirement, the Panel concluded that the US bunted kernel standard does not provide an equivalent level of protection to the EU requirements for the following reasons:

- the EU requires absence of the organism on grain, while the US bunted kernel standard tests for disease symptoms on grain (i.e. for bunted kernels). In the US bunted kernel standard, the presence of teliospores is tested only on the suspect bunted kernels in order to confirm the identification of the pathogen.

- the results of the simulations showed that, by applying the US bunted kernel standard, teliospores may enter the EU with grain import.

- the US bunted kernel standard can detect diseased grain (bunted kernels) but not healthy grain carrying on its surface teliospores of the organism as contaminants.

- the US bunted kernel standard includes only one time of sampling and testing, at harvest, whereas the current EU requirements require one additional sampling and testing to be made before shipment.

Therefore, the Panel concluded that a level of protection comparable to the present EU requirement could only be warranted by measures which include testing at harvest and before shipment to detect teliospores both infecting and contaminating grain imported into the EU.

DOCUMENTATION PROVIDED TO EFSA

1. Letter of Dr. Murali Bandla, United States Department of Agriculture, Animal and Plant Health Inspection Service, addressed to the Acting Head of Unit of DG SANCO E1 Ms D. André, dated April 1st 2009.

2. United States Department of Agriculture, Animal and Plant Health Inspection Service (USDA-APHIS) (2008). Quantitative pathway analysis: likelihood of Karnal bunt, (*Tilletia indica* M.), introduction as a result of the importation of United States wheat for grain into the European Union and desert durum wheat for grain into Italy.

3. References and personal communications cited in USDA APHIS (2008), kindy provided by USDA APHIS.

4. @Risk file used in the quantitative pathway analysis (USDA APHIS, 2008), kindly provided by USDA APHIS.

REFERENCES

Agarwal VK, Singh DV and Mathur SB, 1993. Karnal bunt (*Tilletia indica*). In: Seed-borne Diseases and Seed Health Testing of Wheat.. Eds Mathur S B and Cunfer B M. Danish Gov. Inst. Seed Pathol., Jordbrugsforlaget, Frederiksberg, Denmark, 31-43.

Aggarwal, VK and Verma HS, 1983. A simple technique for the detection of Karnal bunt infection in wheat seed samples. Seed Research 11:100-102.

Allen TW, Maples HW, Workneh F, Stein JM and Rush CM, 2008. Distribution and recovery of *Tilletia indica* teliospores from regulated wheat fields in Texas. Plant Disease 92, 344-350.

Anderson, K.B. and Noyes, R.T. No Date. Grain storage costs in Oklahoma. Oklahoma Cooperative Extension Service Fact Sheet F-210. 2 pp.

Arizona Grain Research and Promotion Council (2005). Annual newsletter. Fall 2005, pp. 10. Available at http://www.desertdurum.com/AGRPC%20Report/AGRPC%20reports.htm (last accessed on 04/05/2010).

Arizona Grain Research and Promotion Council (2006). Annual newsletter. Fall 2006, pp. 10. Available at http://www.desertdurum.com/AGRPC%20Report/AGRPC%20reports.htm (last accessed on 04/05/2010).

Arizona Grain Research and Promotion Council (2008). Annual newsletter. Fall 2008, pp. 10 Available at http://www.desertdurum.com/AGRPC%20Report/AGRPC%20reports.htm (last accessed on 04/05/2010).

Aujla SS, Sharma YR, Chand K, Sawney S S 1977. Influence of weather factors on the incidence and epidemiology of Karnal bunt disease of wheat in the Punjab. Indian J. Ecol. 4:71-74.

Babadoost M, 2000. Comments on the zero-tolerance quarantine of Karnal bunt of wheat. Plant disease 84, 711-712.

Bansal R, Singh DV, Joshi LM, 1984. Effect of liquid nitrogen on germination of teliospores of Karnal bunt. Indian Phytopathology 37, 368–9.

Bechtel, D.B.; Wilson, J.D.; Eustace, W.D.; Behnke, K.C.; Whitaker, T.; Peterson, G.L. and Sauer, D.B. 1999. Fate of dwarf bunt fungus teliospores during milling of wheat into flour. Cereal Chemistry. 76(2): 270-275.

Bedi PS and Meeta M, 1981. Effect of 'Karnal' bunt on weight and germination of wheat grain and subsequent methabolism of seedlings. Indian Phytopathology 34, 114 (abstract).

Bedi PS, Meeta M and Dhiman JS, 1981. Effect of Karnal bunt on weight and quality of the grains. Indian Phytopathology 34, 330-333.

Bedi SKS, Sikka MR and Mundkur BB, 1949. Transmission of wheat bunt due to *Neovossia indica* (Mitra) Mundkur. Ind. Phytopathol., 2, 20-26.

Bhat RV, Deosthale YG, Roy DN, Vijayaraghavan M and Tulpule PG, 1980. Nutritional and toxicological evaluation of Karnal bunt affected wheat. Indian Journal of Experimental Biology 18, 1333-1335.

Bonde MR, Peterson GL and Matsumoto TT, 1989. The Use of Isozymes to Identify Teliospores of *Tilletia indica*. Phytopathology 79, 596-599.

Bonde MR, Peterson GL, Schaad NW and Smilanick JL, 1997. Karnal bunt of wheat. Plant Disease 81, 1370–1377.

California Wheat Commission 2001. Desert durum 2001. Crop Quality Report 2001, pp.4. Available at http://www.californiawheat.org/quality_info.htm (last accessed on 10/05/2010).

California Wheat Commission 2002. Desert durum 2002. Crop Quality Report 2002, pp.4. Available at http://www.californiawheat.org/quality_info.htm (last accessed on 10/05/2010).

California Wheat Commission 2003. Desert durum 2003. Crop Quality Report 2003, pp.4. Available at http://www.californiawheat.org/quality_info.htm (last accessed on 10/05/2010).

California Wheat Commission 2004. Desert durum 2004. Crop Quality Report 2004, pp.4. Available at http://www.californiawheat.org/quality_info.htm (last accessed on 10/05/2010).

California Wheat Commission 2005a. Hard red wheat 2005, hard white wheat 2005. Crop Quality Report 2005, pp. 8. Available at http://www.californiawheat.org/quality_info.htm (last accessed on 10/05/2010).

California Wheat Commission 2005b. Desert durum 2005. Crop Quality Report 2005, pp. 4 Available at http://www.californiawheat.org/quality_info.htm (last accessed on 10/05/2010).

California Wheat Commission 2006a. Hard red wheat 2006, hard white wheat 2006. Crop Quality Report 2006, pp. 8. Available at http://www.californiawheat.org/quality_info.htm (last accessed on 10/05/2010).

California Wheat Commission 2006b. Desert durum 2006. Crop Quality Report 2006, pp. 4. Available at http://www.californiawheat.org/quality_info.htm (last accessed on 10/05/2010).

California Wheat Commission 2007. Hard red wheat 2007, hard white wheat 2007. Crop Quality Report 2007, pp. 8. Available at http://www.californiawheat.org/quality_info.htm (last accessed on 10/05/2010).

California Wheat Commission 2007b. Desert durum 2007. Crop Quality Report 2007, pp. 4. Available at http://www.californiawheat.org/quality_info.htm (last accessed on 10/05/2010).

California Wheat Commission 2008. Hard red wheat 2008, hard white wheat 2008. Crop Quality Report 2008, pp. 8. Available at http://www.californiawheat.org/quality_info.htm (last accessed on 10/05/2010).

California Wheat Commission 2008b. Desert durum 2008. Crop Quality Report 2008, pp. 4. Available at http://www.californiawheat.org/quality_info.htm (last accessed on 10/05/2010).

California Wheat Commission 2009. Hard red wheat 2009, hard white wheat 2009. Crop Quality Report 2009, pp. 8. Available at http://www.californiawheat.org/quality_info.htm (last accessed on 10/05/2010).

California Wheat Commission 2009b. Desert durum 2009. Crop Quality Report 2009, pp. 4. Available at http://www.californiawheat.org/quality_info.htm (last accessed on 10/05/2010).

Castlebury LA, 1998. Morphological characterization of *Tilletia indica* and similar fungi. In: Proc. Bunts and Smuts of Wheat: An International Symposium. Eds Malik VS and Mathre DE. North Carolina. North American Plant Protection Organization, Ottawa, Canada.97-105.

Castlebury LA, Carris LM. 1999. *Tilletia walkeri*, a new species on *Lolium multiflorum* and *L. perenne*. Mycologia 91, 121–131.

Castlebury LA, Carris LM and Vánky K, 2005. Phylogenetic analysis of *Tilletia* and allied genera in order Tilletiales (Ustilaginomycetes; Exobasidiomycetidae) based on large subunit nuclear rDNA sequences. Mycologia 97, 888–900.

Castro-Duarte A, Fuentes-Dávila G, Figueroa-López P, 2005. Viabilidad de teliosporas de *Tilletia indica* Mitra después de ser ingeridas por diferentes tipos de aves comunes en el sur de Sonora, México. Revista Mexicana de Fitopatología 23, 19-23.

Chib HS, Kalha CS, Gupta BR, Tikoo ML, Gupta RS, 1990. Studies on the longevity of *Neovossia indica* (the incitant of Karnal bunt of wheat) in soil. Plant Disease Research 5(Special), 17–8.

Chona BL, Munjal RL and Adlakha KL, 1961. A method for screening wheat plants for resistance to Karnal bunt (N. indica). Proc. Indian Natl. Sci. Acad. B61, 479-486.

Crous P W, van Jaarsveld AB, Castlebury L A, CarrisL M, FrederickR D, Pretorius Z A 2001. Karnal bunt of wheat newly reported from the African continent. Plant Dis. 85, 561.

Cunfer BM, Douce GK, Padgett GB and Miller AE, 1997. Karnal bunt *Tilletia (Neovossia) indica*. The University of Georgia. Cooperative Agricultural Pest Survey Program Publication. GACAPS0297-1.

Da Luz W C, Mendes M A S, Ferreira M A S V, Urben A F, 1993. *Tilletia indica* em trigo no sul do Rio Grande do Sul e medidas para erradicação. Fitopatologia Brasileira, Brasília, DF, 18: 329 (Abstract).

DesertDurum®.Com, online. Homepage of the Desert Durum® industry of Arizona and California. Available at http://www.desertdurum.com/ (last accessed on 04/05/2010).

Dowell FE, Boratynski TN, Ykema RE, Dowdy AK, Staten, R T, 2002. Use of optical sorting to detect wheat kernels infected with *Tilletia indica*. Plant Dis. 86, 1011-1013.

DPHQ (Directorate of Plant Health and Quality), 2001. Karnal bunt. Technical manual. Compiled by Division Plant Health Promotion, Directorate Plant Health and Quality (DPHQ) Department of Agriculture, Republic of South Africa. Available at http://www.nda.agric.za/docs/GenPub/karnalbunt.htm (last accessed on 10/05/2010).

Duran R, 1972. Aspects of teliospore germination in North American smut fungi. II. Canadian Journal of Botany 50, 2569-2573.

Durán R, Cromarty R 1977. *Tilletia indica*: A heterothallic wheat bunt fungus with multiple alleles controlling incompatibility. Phytopathology 67, 812-815.

EFSA 2006. Guidance of the scientific committee on a request from EFSA related to uncertainties in dietary exposure assessment. The EFSA Journal 438, 1-54.

EFSA, 2010. Technical report of EFSA prepared by the Assessment Methodology Unit on quantitative pathway analysis of the exposure of the wheat production area with *Tilletia indica* M. teliospores one year after importation of US wheat for grain into the EU and desert durum wheat into Italy. Appendix B to EFSA PLH Panel Scientific opinion on a quantitative pathway analysis of the likelihood of *Tilletia indica* M. introduction into EU with importation of US wheat. EFSA Technical Report (2010), in press, 1-94.

EPPO 2004. EPPO Standards, Diagnostic protocols for regulated pests, PM 7/29. Bulletin OEPP/EPPO Bulletin 34, 155 –157.

European Flour Millers (European Flour Milling Association), online. Flour milling: facts and figures. Available at http://www.flourmillers.eu/default.asp?structureID=320 (last accessed on 10/05/2010).

European Flour Millers (European Flour Milling Association), 2010. Personal communication: information on EU wheat importation pathway and milling process. Email from Laurent Reverdy, dated 02/03/2010.

Eurostat, online a. Eurostat, statistical office of the European Commission. Statistics. Database on crops products (excluding fruits and vegetables) (annual data) (apro_cpp_crop). Available at http://epp.eurostat.ec.europa.eu/portal/page/portal/agriculture/data/database (last accessed on 10/05/2010).

Eurostat, online b. Eurostat, statistical office of the European Commission. Statistics. External trade database (ComExt). Available at http://epp.eurostat.ec.europa.eu/portal/page/portal/external_trade/data/database (last accessed on 10/05/2010).

Ferreira MASV, Tooley PW, Hatziloukas E, Castro C and Schaad NW, 1996. Isolation of a species-specific mitochondrial DNA sequence for identification of *Tilletia indica*, the Karnal bunt of wheat fungus. Appl. Environ. Microbiol. 62, 87-93.

FGIS. No Date. Italy’s wheat imports as reported by FGIS. Federal Grain Inspection Service. Courtesy of Frahm, J. 2006. Vice President of Planning. U.S. Wheat Associates. Washington, DC. *(copy kindly provided by USDA APHIS).*

Forster RL, Goates BJ, 1997. Karnal bunt. University of Idaho. CIS 1067, 6 pp. Available at http://www.cals.uidaho.edu/edComm/pdf/CIS/CIS1067.pdf (last accessed 10/05/2010).

Frederick RD, Snyder KE, Tooley PW, Berthier-Schaad Y, Peterson GL, Bonde MR, Schaad NW and Knorr DA, 2000. Identification and differentiation of *Tilletia indica* and *Tilletia walkeri* using PCR. Phytopathology 90, 951–960.

Frittelli, J.F. 2005. Grain transport: modal trends and infrastructure implications. CRS report for Congress. Congressional Research Service. 20 pp.

Fuentes-Dávila G, 1997. Carbón parcial del trigo: situación actual y perspectivas. Memorias del primer simposio internacional de trigo, 7 al 9 de Abril de 1997, Cd. Obregón, Sonora, México, 105-118.

Fuentes-Dávila G, Goates BJ, Thomas P, Nielsen J and Ballantyne B, 2002. Smut diseases. In: Bread wheat. Improvement and production. Eds. Curtis BC, Rajaram S and Gómez Macpherson H. FAO Plant Production and Protection Series. Available at http://www.fao.org/docrep/006/y4011e/y4011e0h.htm#bm17 (last accessed on 23/05/2010).

GAM (Groupement des associations meunières des pays de l’U.E.), 2008. Manual on the European flour milling industry. GAM, Brussels (BE), 117 pp.

Garrett KA, Bowden RL 2002. An Allee effect reduces the invasive potential of *Tilletia indica*. Phytopathology. 92: 1152-1159.

Goates BJ, 2007. Personal communication from Goates BJ, United States Department of Agriculture-Agricultural Research Service, Aberdeen, Idaho. Personal communication cited in USDA APHIS (2008) *(copy kindly provided by USDA APHIS).*

Goates BJ, 2008. Quantification of *Tilletia indica* teliospores in sori of commercially harvested wheat grains. Phytopathology 98,S60 (abstract).

Holton CS, 1949. Observations on *Neovossia indica*. Indian Phytopathology 2, 1-5.

Inman AJ, Hughes KJD, Bowyer RJ 2003. EU recommended protocol for the diagnosis of a quarantine pathogen, *Tilletia indica*. Central Sciences Laboratory, York, UK.

Italmopa (Associazione Industriale Mugnai d'Italia), online. Homepage of the Italian milling industries association. Available at http://www.italmopa.it/newfiles/newhome.html (last accessed on 05/05/2010).

Italmopa (Associazione Industriale Mugnai d'Italia), 2010. Personal communication: presentation on the wheat importation pathway and the Italian durum wheat milling industry. Technical hearing at the 7th meeting of the PLH Panel Working Group on *Tilletia indica*, Parma (IT), 22/01/2010.

ITTS. 2001. Executive summary: Latin America trade and transportation study. Institute for Trade and Transportation Studies. 18 pp.

Jhorar OP, Mavi HS, Sharma I, Mahi GS, Mathauda SS, Singh G, 1992. A biometeorological model for forecasting Karnal bunt disease of wheat. Plant Disease Research 7, 204–9.

Joshi L M, Singh D V, Srivastava K D and Wilcoxson R D, 1983. Karnal bunt: A minor disease that is now a threat to wheat. The Botanical Review 49, 309-330.

Krishna A, Singh RA,1983. Longevity of teliospores of *Neovossia indica* causing Karnal bunt of wheat. Indian J. Mycol. Plant Pathology 13, 97-98.

Levy L, Castlebury LA, Carris LM, Meyer RJ, Pimentel G, 2001. Internal transcribed spacer sequence-based phylogeny and polymerase chain reaction-restriction fragment length polymorphism differentiation of *Tilletia walkeri* and *T. indica*. Phytopathology 91, 935–940.

Martinez WH; Brown WM Jr, Fuentes-Davila G, Gingery RE,Hoffinann JA, Johnsson L, Kahn, R P, Line R F, MacLatchy IA, Mathre DE, Peterson GL, Podleckis EV, Weltzien HC, Yang XB, Bownik T, Jones J.R, Phillips JG, Pitchford JB, Sears R, Stefanski RJ, Weimar M, Whitaker TB, Wilson WW and Yoe CE, 1998. Risk assessment for the importation of US milling wheat containing teliospores of *Tilletia controversa* (TCK) into The Peoples Republic of China. United States Department of Agriculture Agricultural Research Service/World Agricultural Board, 51 pp.

McDonald J G, Wong E and White G P, 2000. Differentiation of *Tilletia* species by rep-PCR genomic fingerprinting. Plant Disease 84, 1121-1125.

Menzi H, 2002. Manure management in Europe: results of a recent survey. In: RAMIRAN 2002. Eds Venglovsky J and Greserova G. 10th International Conference Hygiene Safety, Strbske Pleso, High Tatras, Slovak Republic, May 14–18, pp. 93–102. Available at http://www.ramiran.net/DOC/B2.pdf (last accessed on 10/05/2010).

Miglietta F, 1989. Effect of photoperiod and temperature on leaf initiation rates in wheat (*Triticum* spp.). Field Crops Research 21, 121–30.

Mitra, M, 1931. A new bunt disease of wheat in India. Ann. Appl. Biol. 18. 178-179.

Morgan and Henrion 1990. Uncertainty – A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis. Cambridge, University Press, 1990, 332 pp.

Mundkur BB, 1940. A second contribution towards the knowledge of Indian Ustilaginales. Transactions of the British Mycological Society 24, 312-336.

Murray GM, 2004. Evaluation of published data for *Tilletia indica* to compare existing disease models in relation to data obtained in Workpackages 2, 3 and 4. EU Karnal Bunt Risks Project. Deliverable Report 1·4. Available at http://karnalpublic.pestrisk.net/ (last accessed on 10/05/2010).

Murray GM and Sansford CE, 2005. How *Tilletia indica* overcomes the Allee effect. In: Proceedings of the 15th Biennial Australasian Plant Pathology Society Conference, Geelong, Victoria, Australia. 26th – 29th September 2005.

Murray MG and Brennan JP,1998. The risk to Australia from *Tilletia indica* Mitra, the cause of Karnal bunt of wheat. Australasian Plant Pathology 27, 212-225.

Nagarajan S, 2001. Pest risk analysis for shipping wheat from Karnal bunt (*Tilletia indica*) infected and disease free destinations. A report of consultancy project extended to Dr. S. Nagarajan vide F. No. 2(30)/I.C.I. dt. 19.01.2001 of ICAR, new Delhi: 114 pp.

NAEGA (North American Export Grain Association, Washington, D.C.), 2006. Personal communication cited in USDA APHIS (2008) *(copy kindly provided by USDA APHIS).*

Naudé K, 2002. Karnal bunt in South Africa. Items from South Africa Small Grain Institute. Annual Wheat Newsletter, 49; 137.

Ottman M, 2002. Cultural practices for Karnal bunt control. The University of Arizona, College of Agriculture and Life Sciences, Tucson, Arizona. AZ 1287. Available at http://www.ag.arizona.edu/pubs/crops/az1287.pdf (last accessed on 10/05/2010).

Pascoe IG, Priest MJ, Shivas RG and Cunnington JH, 2005. Ustilospores of *Tilletia ehrhartae*, a smut of *Ehrharta calycina*, are common contaminants of Australian wheat grain, and a potential source of confusion with *Tilletia indica*, the cause of Karnal bunt of wheat. Plant Pathology (Oxford) 54, 161-168.

Peña RJ, Amaya A, del Toro E, 1992. Effect of grain washing and storage of wheat samples (Cultivar Seri M82) with different infection levels of Karnal bunt (*Tilletia indica*) on quality parameters. In: Update on Karnal bunt reaearch in Mexico. Eds Fuentes-Davila G and Hettel GP, Wheat Special Report No. 7. Mexico, DF, CIMMYT, 21-28.

Peterson G, 2006. Personal communication by Peterson G, Biologist. Foreign Disease-Weed Science Research Unit. USDA-ARS-NAA. Fort Detrick, Maryland. Personal communication cited in USDA APHIS (2008) (*copy kindly provided by USDA APHIS*).

Peterson GL, Bonde MR and Phillips JG, 2000. Size-selective sieving for detecting teliospores of *Tilletia indica* in wheat seed samples. Plant Disease 84, 999-1007.

Porter JR, 1984. A model of canopy development in winter wheat. Journal of Agricultural Science 102, 383–92.

Posner ES, Fernandez B and Huang DS, 2006. Desert durum wheat provides high-quality extraction and pasta products. Cereal foods world, 51(5), 268–272.

Rai RC and Singh A, 1982. Estimation of loss of wheat grain weight due to Karnal bunt infection. Indian Journal of Mycology and Plant Pathology, 12(1), 102-103.

Rattan GS and Aujla SS, 1990. Spore load in Karnal bunt infected wheat grains. Annals of biology, 7(2), 225-228.

Rattan GS and Aujla SS, 1991. Distribution of infection in Karnal bunt infected wheat spike. Annals of biology, 6(2), 179-180.

Riccioni L, Inman A, Magnus HA, Valvassori M, Porta-Puglia A, Conca G, Di Giambattista G, Hugues K, Coates M, Bowier R, Barnes A, Sansford C, Razzaghian J, Prince A and Peterson G, 2008. Susceptibility of European bread and durum wheat cultivars to *Tilletia indica*. Plant Pathology, 57, 612-622.

Rush CM, Stein JM, Bowden RL, Riemenschneider R, Boratynski T and Royer MH, 2005. Status of Karnal bunt of wheat in the United States 1996–2004. Plant Disease, 89, 212–23.

Sánchez-Ramírez CV, 1994. Comparación de sistemas progresivos de lavado y filtrado para la detección de esporas de carbón parcial (*Tilletia indica* Mitra). p. 102. Memorias XXI Congreso Nacional de la Sociedad Mexicana de Fitopatología. Cuernavaca, Morelos, México. Julio 20-22, 1994, 121 pp.

Sansford C E, 1998. Karnal bunt (*Tilletia indica*): An assessment of the significance of the initial detection of *Tilletia indica* Mitra in the USA in early 1996 and the potential risk to the United Kingdom (and the European Union). In: Proc. Bunts and Smuts of Wheat: An International

Symposium. Eds Malik V. S. and Mathre D. E., North Carolina. North American Plant Protection Organization, Ottawa, Canada, 273-302.

Sansford C, Baker R, Brennan J, Ewert F, Gioli B, Inman A, Kelly P, Kinsella A, Leth V, Magnus H, Miglietta F, Murray G, Peterson G, Porta-Puglia A, Porter J, Rafoss T, Riccioni L, Thorne F and Valvassori M, 2006. Risks associated with *Tilletia indica*, the newly-listed EU quarantine pathogen, the cause of Karnal bunt of wheat. EC Fifth Framework Project QLK-19990-01554, 136 pp.

Sansford C, Baker R, Brennan J, Ewert F, Gioli B, Inman A, Kelly P, Kinsella A, Leth V, Magnus H, Miglietta F, Murray G, Peterson G, Porta-Puglia A, Porter J, Rafoss T, Riccioni L, Thorne F and Valvassori M, 2007. Risks associated with *Tilletia indica*, the newly-listed EU quarantine pathogen, the cause of Karnal bunt of wheat. EC Fifth Framework Project QLK5-1999-01554. Summary of Final Project Report, 14 pp. Available at http://lmt.planteforsk.no/pfpntr/karnalpublic/publicsite_summary.pdf (last accessed on 10/05/2010).

Sawyer AJ, Huettel RN and Meyer RJ, 1997. Within-field spatial distribution of *Tilletia indica* (Karnal bunt): Implications for detection surveys. (Abstr.) Phytopathology 87:S85.

Sekhon KS, Saxena AK, Randhawa SK and Jill KS, 1980. Effect of Karnal bunt disease on quality characteristics of wheat. Bulletin of Grain Technology 18, 208-212.

Sekhon KS, Randhawa SK, Saxena AK and Jill KS, 1981. Effect of washing/steeping on the acceptability of Karnal bunt infected wheat for bread, cookie and chapati making. Journal of Food Science and Technology, 18, 1-2.

Semouliers (Union des associations des semouliers des pays de l’UE), online. Documents: monographie. Industrie européenne de la semoulerie-Monographie 2008. Available at http://www.semouliers.org/documents/Monographie%202008.pdf (last accessed on 5/5/2010).

Singh A, Prasad R, 1978. Date of sowing and meteorological factors in relation to occurrence of Karnal bunt of wheat in U. P. Tarai. Indian J. Mycol. Plant Pathol. 8, 2.

Smilanick JL, Dupler M, Goates BJ, JA Hoffman, Clark D and Dobson D, 1986. Germination of teliospores of Karnal, dwarf, and common bunt fungi after ingestion by animals. Plant disease 70, 242-244.

Smiley R W, 1997. Risk assessment for Karnal bunt occurrence in the Pacific Northwest. Plant Disease 81, 689-692.

Smith O, Peterson GL, Beck RJ, Schaad NW and Bonde MR, 1996. Development of a PCR-based methods for identification of *Tilletia indica*, causal agent of Karnal bunt of wheat. Phytopathology 86, 115-122.

Stansbury CD, McKirdy SJ, Diggle AJ and Riley IT, 2002. Modeling the risk of entry, establishment, spread, containment, and economic impact of *Tilletia indica*, the cause of Karnal bunt of wheat, using an Australian context. Phytopathology, 92, 321-331.

Sweeten, J.M. 1991. Summary of TCFA/TAEX survey results: use of feedlot manure for fertilizer, 1991. Communicated by fax from Dr. Brent Bean. Texas A&M Experiment Station. March 29, 2005.

Tan MK, Ghalayini A, Sharma I, Yi J, Shivas R , Priest M and Wright D, 2009. A one-tube fluorescent assay for the quarantine detection and identification of *Tilletia indica* and other grass bunts in wheat. Australasian Plant Pathology, 38, 101–109.

Tan MK and Murray GM, 2006. A molecular protocol using quenched FRET probes for the quarantine surveillance of *Tilletia indica*, the causal agent of Karnal bunt of wheat. Mycological Research 110, 203–210.

Torabi M, Mardoukhi V, Jaliani N, 1996. First report on the occurrence of partial bunt on wheat in the southern parts of Iran. Seed and Plant 12: 8–9 (Persian) and 59–60 (English).

USDA APHIS (United States Department of Agriculture, Animal and Plant Health Inspection Service), 2007. Karnal bunt manual. USDA APHIS, 164 pp. Available at http://www.aphis.usda.gov/import_export/plants/manuals/domestic/downloads/kb.pdf (last accessed on 10/05/2010).

USDA APHIS (United States Department of Agriculture, Animal and Plant Health Inspection Service), 2008. Quantitative pathway analysis: likelihood of karnal bunt, (*Tilletia indica* M.), introduction as a result of the importation of United States wheat for Grain into the European Union and Desert durum wheat for grain into Italy. United States Department of Agriculture-Animal and Plant Health Inspection Service, 105 pp.

USDA APHIS (United States Department of Agriculture, Animal and Plant Health Inspection Service), 2009. National Karnal bunt survey 2009. USDA APHIS, 26 pp. Available at http://www.aphis.usda.gov/plant_health/plant_pest_info/kb/downloads/survey2009.pdf (last accessed 10/05/2010).

USDA NASS (United States Department of Agriculture, National Agricultural Statistics Service), online. Quick Stats. US and all States county data crops. Available at http://www.nass.usda.gov/QuickStats/Create_County_All.jsp (last accessed on 26/01/2010).

USDOT-FHWA. 2005. International freight studies: European Scan. Summary Report. United States Department of Transportation-Federal Highway Administration, 35 pp.

US Wheat Associates (Beijing)/SAGR. No Date. Industry estimates for millfeed distribution losses in China. Chinese State Administration for Grain Reserves. U.S. Wheat Associates. Beijing Office. Data courtesy of Peterson, G. 2006. (*copy kindly provided by USDA APHIS*).

U.S. Wheat Associates, online. Buyer’s guide: glossary of terms. Available at http://www.uswheat.org/buyersGuide/glossary (last accessed on 10/05/2010).

Vimal Mehdi, Joshi LM and Abrol YP, 1973. Studies on chapati quality. vi. Effect of wheat grains with bunts on the quality of *chapattis*. Bulletin of Grain Technology 11, 195-197.

Vocke G and Allen E, 2005. Wheat Outlook/WHS-05k/December 13, 2005 - Economic Research Service, USDA, Table 1, page 11.

Warham EJ, 1986. Karnal bunt disease of wheat: A literature review. Tropical Pest Management 32, 229-242.

Warham EJ and Flores D, 1988. Farmer surveys on the relation of agronomic practices to Karnal bunt disease of wheat in the Yaqui Valley, Mexico. Tropical Pest Management 34, 373-381.

WHO/IPCS, 2008. Uncertainty and data quality in exposure assessment. IPCS harmonization project document; no. 6. Geneva: WHO, 2008.

Wright D, Murray GM and Tan M-K, 2003. National Diagnostic Protocol for the identification of *Tilletia indica*, the cause of Karnal bunt. Department of Agriculture, WA: Perth. Extract available at http://www.padil.gov.au/pbt/index.php?q=node/22&pbtID=130 (last accessed 10/05/2010).

Ykema RE, Floyd JP, Palm ME and Peterson GL 1996. First report of Karnal bunt of wheat in the United States. Plant Disease 80, 1207.

APPENDICES

A. EU WHEAT PRODUCTION AND IMPORT FROM EUROSTAT DATABASES

In the following tables, harvested production, area of production and volume of import are reported for wheat for each EU Member State. For harvested production and area of production, the relevant commodities in the Eurostat Crop products database were “common wheat and spelt” and “durum wheat”. For import, the commodities considered in the Eurostat External trade database (Comext) were “other wheat (including spelt) and meslin, unmilled” and “durum wheat, unmilled”. Databases were last accessed on 10/5/2010.

Table 24: Harvested production of “common wheat and spelt” (1000 tonnes). EU Member States are sorted in the first column according to the figures of the 2009. Data extracted from Eurostat apro_cpp_crop on 10/5/2010.

GEO/TIME	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
European Union (27 Member States)	119134*	112265*	123394	102677	136681	125995	114171*	111771	140424	129818
France	35668	30189	37320	29054	37607	34843	33264	30779	36900	36233
Germany	21578	22814	20792	19225	25377	23642	22366	20790	25950	25125
United Kingdom	16694	11574	15954	14313	15461	14865	14735	13137	17227	14379
Poland	8503	9283	9304	7858	9893	8771	7060	8317	9275	9790
Denmark	4693	4664	4056	4701	4759	4887	4802	4519	5019	5996
Romania	4431	7725	4413	2477	7798	7331	5518	3043	7176	5196
Czech Republic	4084	4476	3867	2638	5043	4145	3506	3939	4691	4358
Hungary	:	:	3868	2918	5953	5049	4336	3958	5594	4346
Bulgaria	3366	4015	4066	1960	3891	3400	:	2377	4610	4000
Spain	5354	3108	4669	4030	4389	3092	3878	5209	5569	3447
Italy	3117	2789	3280	2512	3093	3286	3193	3248	3746	2693
Sweden	2400	2345	2113	2283	2412	2247	1967	2256	2202	2284
Lithuania	1238	1076	1218	1204	1430	1379	810	1391	1723	2100
Belgium	1688	1457	1675	1693	1913	1799	1720	1645	1944	1928
Slovakia	1244	1766	1542	918	1733	1586	1325	1366	1784	1501
Austria	1269	1462	1385	1128	1630	1390	1320	1346	1598	1457
Netherlands	1143	991	1057	1130	1224	1175	1185	1018	1366	1402
Latvia	427	452	520	468	500	677	598	807	990	1036
Finland	538	489	569	679	782	801	684	797	788	887
Greece	408	401	381	323	274	270	432	466	525	500
Ireland	737	769	867	794	1037	802	801	713	951	490
Estonia	147	133	148	145	197	263	220	346	343	346
Slovenia	163	181	175	123	147	141	134	133	160	137
Portugal	182	51	86	36	58	80	242	100	196	96
Luxembourg	61	54	72	69	80	72	76	71	97	91
Cyprus	:	:	:	:	:	:	:	:	:	:
Malta	:	:	:	:	:	:	:	:	:	:

Note: Double column (:) indicates data not available; ,(*) indicates that values were calculated

Table 25: Harvested production of "durum wheat" (1000 tonnes). EU Member States are sorted in the first column according to the figures of the 2009. Data extracted from Eurostat apro_cpp_crop on 10/5/2010.

GEO/TIME	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
European Union (27 Member States)	9760*	8649*	9991*	8766*	12404*	9172*	9095*	8221*	10013*	8675*
Italy	4310	3624	4268	3718	5546	4431	3989	3923	5113	3648
France	1685	1352	1614	1427	2086	2042	2100	1991	2102	2091
Spain	1939	1900	2153	1989	2708	935	1643	1227	1146	1350
Greece	1450	1429	1402	1309	1500	1491	1144	918	1414	1330
Austria	44	46	50	64	89	63	77	53	91	67
Germany	43	24	26	35	50	51	62	38	39	65
Hungary	45	49	43	24	54	39	40	29	37	50
Slovakia	11	34	12	13	32	22	18	14	35	37
Cyprus	10	11	13	14	10	9	7	11	3	15
Portugal	173	103	327	113	235	1	8	3	7	14
Romania	4	10	8	2	14	10	8	1	5	9
Netherlands	:	:	:	:	:	:	:	:	:	0
United Kingdom	6	6	19	14	12	0	0	0	0	0
Belgium	:	:	:	:	:	:	:	:	:	:
Bulgaria	40	63	57	45	70	78	:	14	22	:
Czech Republic	:	:	:	:	:	:	:	:	:	:
Denmark	:	:	:	:	:	:	:	:	:	:
Estonia	:	:	:	:	:	:	:	:	:	:
Ireland	:	:	:	:	:	:	:	:	:	:
Latvia	:	:	:	:	:	:	:	:	:	:
Lithuania	:	:	:	:	:	:	:	:	:	:
Luxembourg	:	:	:	:	:	:	:	:	:	:
Malta	:	:	:	:	:	:	:	:	:	:
Poland	:	:	:	:	:	:	:	:	:	:
Slovenia	:	:	:	:	:	:	:	:	:	:
Finland	:	:	:	:	:	:	:	:	:	:
Sweden	:	:	:	:	:	:	:	:	:	:

Note: Double column (:) indicates data not available; ,* values were calculated

Table 26: EU imports of the trade commodity 04120 by SITC "other wheat (including spelt) and meslin, unmilled". Quantities in tonnes. EU Member States are sorted in the first column according to the trade figures of the 2009. Data extracted from Eurostat Comext database on 10/5/2010.

REPORTER/YEAR	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
EU 27	2549563	4094217	11118460	5142894	5168249	5329119	3706112	4487036	5527696	4318059
Spain	288024	1444384	3897369	962497	1279745	2147632	841416	1117876	2513250	2229577
Italy	1004937	1341143	3550067	1714422	1865458	1720867	1591565	1297333	1285436	1095799
United Kingdom	624027	568263	543057	339498	339017	493213	452983	604543	589439	600293
Greece	77826	293074	1011571	632156	417963	472197	445728	523152	350782	150641
Portugal	57812	81443	513676	125051	104148	137862	31217	99329	280077	69758
Belgium	179701	85010	723914	344327	286505	173760	252263	307033	161529	63516
Netherlands	106807	76260	119927	45200	54588	6834	1954	54240	26682	43808
Romania	45955	35046	54765	623221	581708	11219	3406	249993	11620	17955
Denmark		1500	176988	13442	0	2969		17293	33968	13450
France	106	28339	50089	46	31	8	45	143	3489	8148
Cyprus	38622	31536	60684	52922	65516	95298	41751	32663	31977	7934
Germany	6008	5772	69950	88454	1756	3151	250	37999	21791	5069
Malta	40654	32802	55751	37086	14071	16119	11376	26492	28257	4700
Finland	8050		53181	7240	1003	3994	11341	2987	8935	2469
Poland	4623	3565	4118	7736	3705	0	305	3001	75228	1990
Latvia	23	4	48			5014	998	1000	14782	1649
Slovenia	15705	1180	96	104	8170	54	1625	17523	272	846
Austria	2	1	8897	0	0	0	858	55	222	199
Bulgaria	842	15723	14601	42260	113166	2998	62	27413	5205	130
Czech Republic		0	0	0	4	4	65	35	12	66
Sweden	20873	13393	134393	10371	16	13	5167	5584	7811	44
Ireland	23109	24512	22259	18888	27325	35845	9601	48414	18200	11
Estonia	1828	3458	46593	31638	71		272	5476	2047	5
Hungary	19	3	2	2	4284	3	0	1207	0	2
Lithuania			6466	46335		65	1864	6253	56662	
Luxembourg										
Slovakia	4012	7805							25	

Table 27: EU imports of the trade commodity 04110 by SITC “durum wheat, unmilled”. Quantities in tonnes. EU Member States are sorted in the first column according to the trade figures of the 2009. Data extracted from Eurostat Comext database on 10/5/2010.

REPORTER/YEAR	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
EU27	1305647	1410637	1096503	1723271	1777561	1773068	2006367	1907452	1315645	2075879
Italy	1133103	1225969	933958	1261632	1224482	1287152	1460755	1348462	938589	1570582
Belgium	16151	3635	36126	184919	233322	173882	237971	234255	188196	300867
Netherlands	50949	40974	44577	78521	26234	107348	169336	183823	50516	137105
Poland	17155	63008	31203	56749	21126	22084	28670	33091	17197	18860
Portugal	27504	36635		16423		39323	41661	33377	36875	17619
France	2259	16655	11101	10983	24011	11012	11207		0	13527
United Kingdom	22	1575	15	16334	13355	6771	5418	9548	13472	9551
Finland	5204	1148	8240	1011	2486	3692	3206	6048	3011	4005
Sweden	849	3020	2942	2207	5167	3946		5175	2204	3414
Austria				0		1	2	1	1	150
Slovenia	0	0	0	0		0		549		69
Romania	1460	168	441	1	19901	15	113			67
Germany	123	53	65	1099	2610	13384	45519	545	741	34
Spain	26240		13068	36029	73066	99169		38225	51121	28
Latvia										1
Cyprus	20848	14621	12783	28611	6264	5264				0
Greece	3098	3175	15	28117	108904	5	2505	14354	13722	0
Bulgaria					16504			1	1	
Czech Republic		2					5			
Denmark	5		1492			1	0		0	
Estonia	378		466	621	128					
Hungary	0		12	16	0	0	0		0	
Ireland										
Lithuania										
Luxembourg										
Malta						20				
Slovakia	300									

Table 28: Area of production of "common wheat and spelt" (1000 ha). EU Member States are sorted in the first column according to the figures of the 2009. Data extracted from Eurostat apro_cpp_crop on 10/5/2010.

GEO/YEAR	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
European Union (27 countries)	20847*	21017*	21055*	18999*	20552*	20940*	19070*	19105*	21356*	21641*
France	4911	4460	4895	4524	4831	4855	4793	4783	5065	4733
Germany	2960	2893	3010	2956	3103	3163	3103	2985	3207	3215
Poland	2635	2627	2414	2308	2311	2218	2176	2112	2278	2346
Romania	1938	2543	2295	1734	2292	2472	2009	1973	2109	2180
United Kingdom	:	:	:	:	:	:	:	:	:	1829
Spain	1486	1292	1481	1307	1226	1364	1306	1390	1538	1233
Hungary	1010	1192	1100	1103	1162	1122	1065	1103	1122	1128
Czech Republic	970	923	849	648	863	820	782	811	802	831
Denmark	619	634	577	664	666	676	686	689	638	739
Italy	659	625	682	577	582	603	583	661	702	534
Lithuania	370	352	335	337	355	370	344	355	404	500
Sweden	401	399	339	411	403	354	360	361	361	375
Slovakia	402	438	403	303	362	371	347	357	367	371
Austria	278	276	276	255	273	274	269	278	279	292
Latvia	158	167	154	168	170	188	215	225	257	286
Finland	150	145	174	192	236	215	192	204	220	218
Belgium	213	181	202	199	213	214	210	210	224	211
Greece	160	171	130	124	88	100	165	186	174	173
Netherlands	137	124	135	129	137	136	140	141	157	151
Estonia	69	60	65	67	78	85	91	100	108	114
Ireland	78	85	103	96	103	95	88	84	105	83
Portugal	87	50	42	30	35	121	101	54	85	52
Slovenia	38	39	36	36	32	30	32	32	35	35
Luxembourg	11	10	12	11	12	12	13	13	15	14
Bulgaria	1107	1333	1348	818	1018	1084	:	:	1107	:
Cyprus	:	:	:	:	:	:	:	:	:	:
Malta	:	:	:	:	:	:	:	:	:	:

Note: Double column (:) indicates data not available ,* values were calculated

Table 29: Area of production of "durum wheat" (1000 ha). EU Member States are sorted in the first column according to the figures of the 2009. Data extracted from Eurostat apro_cpp_crop on 10/5/2010.

GEO/YEAR	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
European Union (27 countries)	3748	3821	4007	3902	4110	3668	2984*	2788*	3081	2804*
Italy	1663	1664	1733	1689	1772	1520	1343	1439	1587	1262
Spain	867	885	926	913	949	911	614	413	529	535
Greece	673	761	760	727	751	746	520	437	483	525
France	338	306	336	353	407	423	453	456	428	414
Austria	16	12	13	17	18	16	16	15	18	17
Hungary	15	14	11	11	12	9	10	8	9	14
Germany	9	5	5	7	8	10	12	8	7	11
Slovakia	4	9	3	5	7	5	4	4	7	9
Portugal	139	134	188	144	152	2	3	1	3	7
Cyprus	6	5	6	7	8	5	7	5	5	6
Romania	2	3	3	1	4	4	4	2	2	6
Belgium	:	:	:	:	:	:	:	:	:	:
Bulgaria	15	23	21	23	22	18	:	:	5	:
Czech Republic	:	:	:	:	:	:	:	:	:	:
Denmark	:	:	:	:	:	:	:	:	:	:
Estonia	:	:	:	:	:	:	:	:	:	:
Ireland	:	:	:	:	:	:	:	:	:	:
Latvia	:	:	:	:	:	:	:	:	:	:
Lithuania	:	:	:	:	:	:	:	:	:	:
Luxembourg	:	:	:	:	:	:	:	:	:	:
Malta	:	:	:	:	:	:	:	:	:	:
Netherlands	:	:	:	:	:	:	:	:	:	:
Poland	:	:	:	:	:	:	:	:	:	:
Slovenia	:	:	:	:	:	:	:	:	:	:
Finland	:	:	:	:	:	:	:	:	:	:
Sweden	:	:	:	:	:	:	:	:	:	:
United Kingdom	1	1	2	4	2	0	0	0	0	:

Note: Double column (:) indicates data not available; * values were calculated

B. DETAILED DESCRIPTION OF SIMULATION RESULTS

A detailed description of simulation results is provided in:

EFSA (2010). Technical report of EFSA prepared by the Assessment Methodology Unit on quantitative pathway analysis of the exposure of the wheat production area with *Tilletia indica* M. teliospores one year after importation of US wheat for grain into the EU and desert durum wheat into Italy. Appendix B to EFSA PLH Panel Scientific opinion on a quantitative pathway analysis of the likelihood of *Tilletia indica* M. introduction into EU with importation of US wheat. EFSA Technical Report (2010), in press, 1-94.