Heliyon

Received:
3 December 2018
Revised:
12 February 2019
Accepted:
12 February 2019

Cite as: Nils Rostoks, Lelde Grantiņa-Ieviņa, Baiba Ieviņa, Velta Evelone, Olga Valciņa, Inese Aleksejeva. Genetically modified seeds and plant propagating material in Europe: potential routes of entrance and current status. Heliyon 5 (2019) e01242. doi: 10.1016/j.heliyon.2019.e01242

Review Article

Genetically modified seeds and plant propagating material in Europe: potential routes of entrance and current status

Nils Rostoks [a,*], **Lelde Grantiņa-Ieviņa** [b], **Baiba Ieviņa** [c], **Velta Evelone** [c], **Olga Valciņa** [b], **Inese Aleksejeva** [d]

[a] *Faculty of Biology, University of Latvia, 1 Jelgavas Street, LV-1004, Latvia*

[b] *Institute of Food Safety, Animal Health and Environment "BIOR", 3 Lejupes Street, Riga, LV-1076, Latvia*

[c] *State Plant Protection Service, 36 Lielvardes Street, Riga, LV-1006, Latvia*

[d] *Biotechnology and Quality Division, Veterinary and Food Department, Ministry of Agriculture, 2 Republic Square, Riga, LV-1981, Latvia*

[*] Corresponding author.

E-mail address: nils.rostoks@lu.lv (N. Rostoks).

Abstract

Genetically modified organisms (GMO), mainly crop plants, are increasingly grown worldwide leading to large trade volumes of living seeds and other plant material both for cultivation and for food and animal feed. Even though all the traded GMOs have been assessed for their safety with regards to human and animal health and the environment, there still are some concerns regarding the potential uncontrolled release in the environment of authorized or unauthorized GM plants. In this review, we identify the possible entrance routes of GM seeds and other propagating plant material in the EU which could be linked to unauthorized release of GMOs in the environment. In addition, we discuss the situation with GM plant cultivation in some non-EU countries in terms of potential risks for GM seed imports. The available body of information suggests that GM seeds and plant propagating material can enter the EU due to problems with labeling/traceability of GM seed lots, contamination of conventional seed

https://doi.org/10.1016/j.heliyon.2019.e01242

lots and accidental release into the environment of grains imported for food and animal feed. Even though cases of uncontrolled release of authorized GMOs, as well as, release of unauthorized GMOs have been reported, they can be generally attributed to adventitious and technically unavoidable presence with little environmental impact. In conclusion, the probability of GM seeds and plant propagating material illegally entering the cultivation in EU is unlikely. However, specific monitoring programs need to be established and maintained to facilitate the compliance of European farmers with the current GMO legislation.

Keywords: Biotechnology, Food safety

1. Introduction

Advent of genetic engineering saw rapid development of genetically modified microorganisms which were soon followed by GM plants in 1980-ties (Caplan et al., 1983). The first generation of GM plants were commercialized in 1996 and since then increasing agricultural land areas have been used for GM plant cultivation exceeding185.1 million Ha in 2016 and growing to 189.8 million Ha in 2017 (ISAAA, 2016, 2017). The main commercially grown GM crops are maize, soybean, oilseed rape and cotton, although many other crop plants have been modified to express novel traits (Kamthan et al., 2016). The main agricultural areas used for GM plant cultivation are in the United States of America, Brazil, Argentina, Canada and India (each over 10 million Ha in 2017), while only two European countries, Spain and Portugal grew GM crops on a total of approximately 131,000 Ha (ISAAA, 2017). The main novel traits are tolerance to glyphosate and glufosinate ammonium herbicides and resistance to insect pests achieved by expressing *Bacillus thuringiensis* toxins, which are often combined by conventional crossing in so called stacked events. GM plants are regulated worldwide, generally and in exception to Canada, on the basis of process by which the plants were created, i.e., genetic engineering (Davison and Ammann, 2017). GM plants in the EU can be authorized for cultivation in accordance to the Directive 2001/18/EC on the deliberate release of GMOs into the environment, or for food and feed import and processing according to regulation 1829/2003. Directive 2015/412 amends Directive 2001/18/EC regarding the possibility for the Member States (MS) to restrict or prohibit the cultivation of GMOs in their territory, while the Directive 2018/350 amends the Directive 2001/18/EC regarding the environmental risk assessment of GMOs. In addition, Regulation 503/2015 provides further guidance on implementation of Regulation 1829/2003. Regulation 1830/2003 sets the requirements for labeling and traceability of GMOs and the traceability of food and feed products produced from GMOs with Commission Recommendation 2004/787/EC providing technical guidance for sampling and detection of GMOs and material produced from GMOs as or in products in the context of Regulation 1830/2003. The independent scientific GMO risk

 https://doi.org/10.1016/j.heliyon.2019.e01242

assessment in the EU is provided by the European Food Safety Authority, while the GMO risk management is carried out by the European Commission (EC) and the National authorities of the MS. Currently, only one GM plant event is authorized for cultivation in the EU, i.e., maize MON810, although its cultivation is prohibited in a number of EU countries and territories by Commission implementing decision 2016/321. MON810 was grown in four of the EU MS (116,870 Ha in 2015, 136,363 Ha in 2016) and only in Spain and Portugal in 2017 (131,535 Ha) and covered 28.2% of the total maize cultivation area in Spain in 2015 (de la Cruz, 2016; ISAAA, 2016, 2017). While the cultivation of GM plants in the EU is restricted to a single maize event MON810, there are over 50 GM plant events that are authorized in the EU for food and feed import and processing (https://ec.europa.eu/food/plant/gmo/eu_register_en). In terms of seed (grain) import for food and feed, EU is estimated to import roughly 30 million tons of GM soybean on a yearly basis (~85% of total soybean import), between 0.5 and 3 million tons of GM maize (5−25% of total maize imports), and less than 0.5 million tons of GM rapeseed (5−10% of total rapeseed imports). Additionally, smaller amounts of cottonseed are imported to the EU, but the proportion of GM cottonseed is difficult to estimate. Although trade data are relatively unreliable, because they do not differentiate between conventional and GM commodities, there is a clear indication that soybean is a major source of GM imports (both whole beans and protein meal) in the EU, which is linked to the high import dependency. Overall, EU is 70% dependent on imports of protein-rich crops, such as soybean, which are important for production of animal feed (European Commission, 2016).

According to European Seed, EU is the leading seed importer (import value 3.6 billion EUR), as well as the largest seed exporter (export value 4.9 billion EUR) in the world. GM seed trade is regulated worldwide and in the EU. EU legislation on the marketing of seed and plant propagating material consists of 12 basic legislative acts (http://ec.europa.eu/food/plant/plant_propagation_material/legislation/review_eu_rules_en). According to the legislation, seeds are generally classified into groups of species, such as, fodder plant seeds, cereal seeds, propagating material of ornamental plants, vine and vegetables, seed potatoes, forest reproductive material etc. Since many of the legislative acts date back to 1960s and 1970s, EC is currently in the process of reviewing the legislation, which is often outdated with regards to modern biotechnology and plant breeding including genetic engineering of crop plants. GM seed are included within the EU legislation of seed and plant propagating material based on Council Directive 98/95/EC of 14 December 1998 amending, in respect of the consolidation of the internal market, GM plant varieties and plant genetic resources, Directives 66/400/EEC, 66/401/EEC, 66/402/EEC, 66/403/EEC, 69/208/EEC, 70/457/EEC and 70/458/EEC on the marketing of beet seed, fodder plant seed, cereal seed, seed potatoes, seed of oil and fibre plants and vegetable seed and on the common

https://doi.org/10.1016/j.heliyon.2019.e01242

catalogue of varieties of agricultural plant species. Other relevant sampling and testing guidelines for GM seed testing are developed by the International Seed Testing Association (ISTA), which promote uniform application of these procedures for evaluation of seeds moving in international trade, including seeds of GM plants which may present unique challenges for testing (Cooke, 1999).

Even though the plant biotechnology industry is well regulated, there are concerns of unintended cultivation of GM crops. Those can be related to biological characteristics of a crop that may facilitate their uncontrolled spread in the environment, large trade volumes of agricultural products and commodities that make segregation measures inefficient, or to deliberate cultivation of unauthorized GM crops. Current review identifies potential routes of entrance of GM seeds and plant propagating material in the EU and evaluates their potential impact.

2. Main text

2.1. GMO seed testing in the EU

The European Network of GMO Laboratories (ENGL) Working Group on "Seed Testing" (WG-ST) analyzed current situation with the detection of unintended presence of GM seed in conventional seed lots (Hochegger et al., 2015). Reports of the EC Food and Veterinary Office (FVO) audits on the official GMO control in Portugal, Spain, Germany, France, The Netherlands, Poland and Slovakia between 2009 − 2013 indicated that the plans for seed control by competent authorities vary among MS (DG (SANCO), 2011a,b,c, 2012a,b, 2013a,b). Some MS applied ISTA rules for seed testing, while other MS implemented national guidelines or adhered to general testing principles, and in some cases no clear criteria were identified. The reports of the audit found that in most cases MS monitored presence of GM seed in conventional seed lots of maize, oilseed rape, soybean and cotton. The labeling threshold for GMOs authorized in the EU varied from 0% in Slovakia to 0.1% (detection limit) in France and Poland, to 0.5% in Portugal, Spain and the Netherlands, while for non-authorized events positive seed lots were rejected. Monitoring requirements differed among the MS, with Spain requiring testing of all seed lots more than 500 kg, Germany testing 10% of all maize and oilseed rape seed lots, and France testing all maize certified seed lots more than 400 kg, while in the other countries monitoring requirements were less precisely defined. Overall, some cases of above threshold presence of authorized GM events in non-GMO seed assignments were identified in Portugal, Spain, Germany and Poland, while detection of non-authorized events was much less common (DG (SANCO), 2011a,b,c, 2012a,b, 2013a,b).

The only GM event that is cultivated in the EU is MON810 Bt maize, and the only EU country with significant acreage of MON810 varieties is Spain. Over 200

https://doi.org/10.1016/j.heliyon.2019.e01242

MON810 varieties are available for farmers in Spain. Seed distribution, cultivation, management and labeling and traceability of MON810 are carefully monitored in the Spain (de la Cruz, 2016). Thus, unauthorized sale of MON810 is unlikely. In several MS including Czech Republic and Slovakia, where field trials of MON810 were carried out, EC audit found that in line with Directive 2001/18/EC specific controls of deliberate release were in place (DG (SANCO), 2013b).

2.2. Information about unauthorized occurrence of GMOs in food and feed in Rapid Alert System for Food and Feed

EC Regulation 178/2002/EC along with the establishment of the European Food Safety Authority (EFSA), also formalized the Rapid Alert System for Food and Feed (RASFF), which is used by the MS national food control authorities to notify any measures regarding food safety, such as recalls of food and feed products and arrestment of imported consignments not complying with food legislations (Kleter et al., 2009). Among the other food and feed-related issues, RASFF accumulates MS reports on cases related to detection of unauthorized GMOs and labeling issues. Here we examine the RASFF reports related to GMOs. As of October 2018, there were 679 records related to unauthorized occurrence of GMOs in food and feed in the EU since 2002 (Fig. 1). The largest number was linked to rice (419 notifications), linseed (119 notifications), papaya (66 notifications) and maize (51 notifications), including derived products. Only a few cases of GM cottonseed, soybean and sweet potato have been reported. Of the 679 notifications, only 203 may be linked to viable seed material based on description in notifications, while the rest of notifications were linked to food and feed ingredients and products. The highest total number of notifications was in 2006 (127) and 2009 (142), which was linked to increased number of notifications for rice and linseed, respectively. The highest number of notifications was from Germany, Austria, United Kingdom, France, The Netherlands,

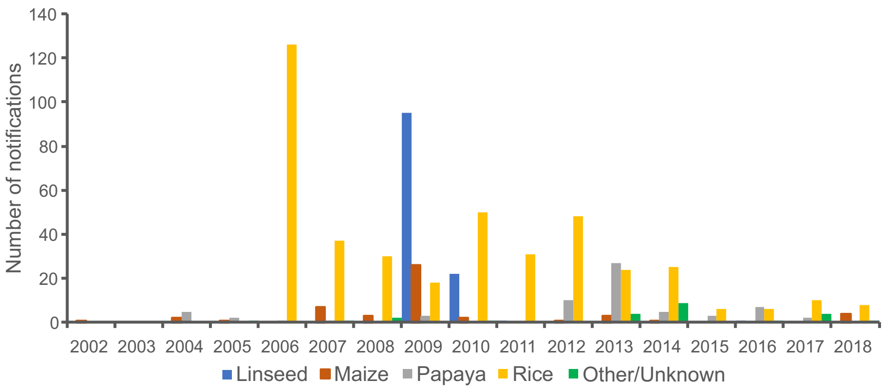

Fig. 1. Number of GMO notifications per year for different plant species in the RASFF database. Data retrieved in October 2018. Other/unknown – cottonseed, soybean, sweet potato and genetically modified microorganisms.

https://doi.org/10.1016/j.heliyon.2019.e01242

Italy, Sweden and Finland (Fig. 2). The overall trend appears to be towards decreased number of notifications (Fig. 1), which may indicate better regulatory compliance. However, the number of notifications may also depend on the available funding for monitoring programs, which depends on perceived urgency for monitoring. The large number of notifications for linseed, for instance, was related to increased monitoring after the contamination of conventional flax with GM variety CDC Triffid was discovered.

2.3. GMO contamination register

GMO Contamination Register (http://www.gmcontaminationregister.org/) is a publicly available database on incidents of contamination arising from intentional or accidental release of GM organisms (Price and Cotter, 2014). Unlike RASFF it attempts to catalogue spillage and contamination of GM seeds all over the world, not just the Europe. Database spanning the time period from 1997 to 2016 contains 448 entries from 64 countries. In that time frame there have been 13 registered cases of maize seed, 11 cases of oilseed rape, seven cases of soybean, four cases of sugar beet and one case each of zucchini, cottonseed and potato contamination in the EU. Most of the cases were registered in the early 2000s, e.g., in 2001 an independent laboratory in Austria reported presence of GM events Bt11 (Novartis, now Syngenta) and MON810 or MON809 (Monsanto) in a conventional maize hybrid. Bt11 is authorized in the EU for food and feed import, but not for cultivation, while MON810, but not MON809, is authorized also for cultivation, although its cultivation is prohibited in a number of EU countries and territories by the Commission implementing decision (EU) 2016/321. The two latest reported cases were in 2014 in Romania (GTS 40-3-2 soybean) and in 2015 in the United Kingdom (oilseed rape). The main reasons for the contamination were identified as foreign pollination or seed contamination with authorized or unauthorized events of seed material imported from outside the EU. Illegal GM soybean cultivation was detected in three cases in Romania after accession to the EU, e.g., Romanian National Environmental Guard (note No. 2088/26.09.2007) reported illegal cultivation of GM soybean on

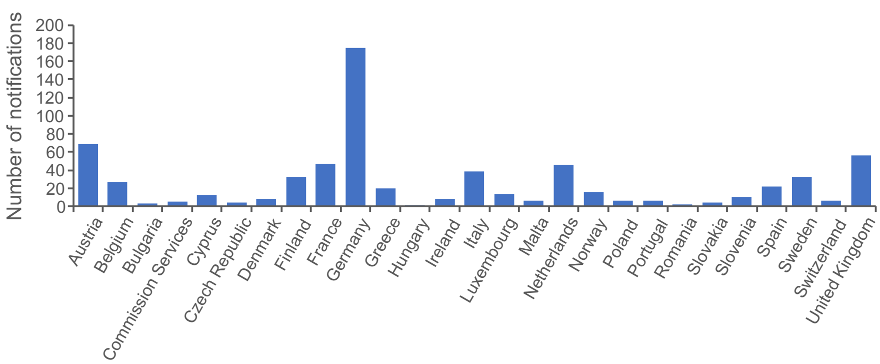

Fig. 2. Number of GMO notifications per European country in the RASFF database.

https://doi.org/10.1016/j.heliyon.2019.e01242

290 ha in the Bihor County. In addition, one case of illegal cultivation of soybean was registered in Serbia in 2005. The GMO Contamination Register has not been updated in the past two years.

2.4. Literature search on GMO seed contamination

Literature search was carried out using Scopus and Clarivate Analytics Web of Knowledge databases without date limitation for English language publications. The following keyword and Boolean operator combination was used for Scopus search: "TITLE-ABS-KEY (genetically modified) OR TITLE-ABS-KEY (transgenic) AND TITLE-ABS-KEY (seed) AND TITLE-ABS-KEY (import) OR TITLE-ABS-KEY (export) OR TITLE-ABS-KEY (contamination)", or "TITLE-ABS-KEY (genetically modified) OR TITLE-ABS-KEY (transgenic) OR TITLE-ABS-KEY (gm) OR TITLE-ABS-KEY (GMO) AND TITLE-ABS-KEY (seed) OR TITLE-ABS-KEY (grain) OR TITLE-ABS-KEY (plant material) AND TITLE-ABS-KEY (import) OR TITLE-ABS-KEY (export))". Similar search using the same keywords was conducted also in Clarivate Analytics Web of Knowledge Core Collection database: "TS=(genetically modified OR transgenic OR gm OR GMO) AND TS=(seed OR grain OR plant material) AND TS=(import OR export)". The abstracts of 356 original research papers or reviews in English language identified in literature searches were screened for relevance to GM seeds and plant propagating material. Of these, 59 papers were selected as relevant for the topic of review and are described below.

Literature search identified numerous publications on general issues of risk management strategies related to GM seed movement, e.g., on transboundary movement of living modified organisms (LMO), market regulations, testing strategies, development of testing methods and database development (Açikgöz et al., 2002; Cantrill, 2008; Cummings, 2002; De Guzman, 2004; Fernandes et al., 2014; Fitting, 2008; Gerdes et al., 2012; Ghosh and Ramanaiah, 2000; Hileman, 2000; Hisano and Altoé, 2008; Horak et al., 2015; Kimani and Gruère, 2010; Kruger et al., 2012; Mousa, 2011; Mulvaney and Krupnik, 2014; Pascher et al., 2017; Putnam et al., 2016; Ryan and Smyth, 2012; Roberts et al., 2015; Rola et al., 2010; Sanchez and Leon, 2016; Santos et al., 2016; Sarmadi et al., 2016; Singh and Randhawa, 2016; Traynor and Komen, 2002; Zafar, 2007; Zhang and Pang, 2009).

The number of publications related to contamination by GM seeds and plant propagating material identified by the literature search was relatively small reflecting general lack of information on these issues. Most of the publications were related to GM grains imported for food and feed purposes, which may escape in the environment (Aono et al., 2011; Cowan, 2014; Devos et al., 2012; Gamarra et al., 2011; Goto et al., 2017; Han et al., 2015; Hanzer et al., 2012; Hecht et al., 2014; Yamaguchi et al., 2003; Kawata et al., 2009; Kim et al., 2006; Lamb and Booker,

https://doi.org/10.1016/j.heliyon.2019.e01242

2011; Macias-De Ia Cerda et al., 2012; Milcamps et al., 2009; Nikolic et al., 2010; Nishizawa et al., 2009; Nishizawa et al., 2016; Nishizawa et al., 2010; Park et al., 2010; Santa-Maria et al., 2014; Schoenenberger and D'Andrea, 2012; Schulze et al., 2015; Schulze et al., 2014; Serratos-Hernandez et al., 2007; Turkec et al., 2016a,b; Zdjelar et al., 2014). Majority of the cases of occurrence of GM seeds have been detected outside European Union, e.g., in Japan, Korea, Mexico or Argentina, and those have been linked to sites of seed import and transport routes. Presence of GT73 glyphosate-resistant oilseed rape populations were detected in Argentina as herbicide tolerant weeds in the fields of glyphosate tolerant soybeans, even though the GT73 oilseed rape is not authorized for cultivation in Argentina. The origin of this event was not determined; however, the authors hypothesized that it came either from unauthorized transgenic oilseed rape crops cultivated in the country or as seed contaminants in imported oilseed rape cultivars or other seed imports (Pandolfo et al., 2016). Illegal introduction of Bt cotton has been reported in Pakistan, before formal regulation was introduced, and approvals granted (Cheema et al., 2016). RASFF also reported imports of unauthorized GM rice into the EU from Pakistan, where it was not supposed to be grown (Sajjad et al., 2016). Most of the cases of contamination were reported for oilseed rape, soybean and maize reflecting the status of commercialized GM crops (ISAAA, 2017) and the exports of major agricultural commodities. However, in some cases non-commercial GM plants have been detected, e.g., GM flax in Canada (Booker and Lamb, 2012; Young et al., 2015; Lamb and Booker, 2011), or GM wheat in the US (Cowan, 2014).

Only a few cases are reported for the European countries including import of Bt10 contaminated maize from the US into the EU for use in food production (Macilwain, 2005) or import of Pioneer Hi-Bred maize hybrids, Ulla and Benicia, to Switzerland containing *Bacillus thuringiensis* genes from a GM event of maize (Furst, 1999).

Imported GM grains for food and feed can theoretically result in seed contamination. In this scenario, the seed contamination is related to inadvertent release of GM grains into environment along the transportation routes or at processing sites, where depending on crop biology and environmental conditions volunteer populations can become established. These volunteer populations can serve as pollen donors for nearby fields of related non-GM crops. GM glyphosate-tolerant oilseed rape contamination was reported in Switzerland along the transport routes (Hecht et al., 2014; Schoenenberger and D'Andrea, 2012; Schulze et al., 2014). Considering that GM oilseed rape is banned both for cultivation and import in Switzerland, the contamination has been linked to low level contamination of imported wheat with GM oilseed rape (Schulze et al., 2015). The establishment of feral herbicide-tolerant oilseed rape populations were facilitated by herbicide management of weeds along the railway routes. Recent study of feral oilseed rape near oil mills and seed processing facilities along the river Rhine found only one transgenic (GT73) plant out of

https://doi.org/10.1016/j.heliyon.2019.e01242

1918 (Franzaring et al., 2016). Occurrence of GM oilseed rape was detected in animal feed samples, but not in seeds for cultivation in Croatia (Nikolic et al., 2010), while GM soybean, maize and oilseed rape were detected in samples of animal feed in Serbia and Poland, although the presence of viable seeds was not demonstrated (Sieradzki et al., 2017; Zdjelar et al., 2014). Testing of soybean seeds certified for cultivation in 2010−2011 in Croatia did not identify presence of GM contamination (Hanzer et al., 2012). Deliberate cultivation of GM soybean was identified in Romania after its accession to the EU in 2007, which was likely linked to the cultivation of Roundup Ready soybean (event GTS 40-3-2) before becoming EU member state (Otiman et al., 2008; Zaulet et al., 2009).

Even though spread of GM plants is often hypothesized to occur through cross-pollination with compatible non-GM crop plants or wild species, the literature search reported only a limited number of cases demonstrating transfer of transgenic pollen, e.g., for maize in South Africa (Viljoen and Chetty, 2011) or oilseed rape in Japan (Tsuda et al., 2012). In summary, even though it is possible that imported GM seed material can be inadvertently introduced to the EU environment and, in some cases, depending on species fitness, can establish persisting plant populations, e.g., oilseed rape, the available evidence suggests that probability of gene transfer from persisting population to crop plants via hybridization is very low (Belter, 2016; Devos et al., 2012).

Conclusion from the literature search is that the number of documented cases of GM contamination is relatively low and that the reported cases are often related to plant grains imported for food and feed. However, there is little evidence that grains imported for food and feed would lead to contamination of seeds for cultivation. Furthermore, there is no evidence that grains imported for food or feed was intentionally used for cultivation.

2.5. Other sources of contamination

Recently, petunias genetically modified to express orange flower color were identified worldwide (Bashandy and Teeri, 2017; Servick, 2017). They apparently originate from the transformation event with maize *A1* gene encoding dihydroflavonol-4-reductase with specificity for dihydrokaempferol resulting in increased level of pelargonidin-type anthocyanins (Meyer et al., 1987), which in certain genetic backgrounds can lead to bright orange flower color (Oud et al., 1995). While any GM plants including ornamental plants, such as, carnation, must undergo a thorough safety assessment for authorization before the release into European market, the application for authorization of GM petunia has never been submitted to the EU competent authorities. Thus, the GM petunia seed and planting material, which was widely available in the EU, was never authorized. Even though the potential consequences for the human and animal health and the environment are negligible

https://doi.org/10.1016/j.heliyon.2019.e01242

considering the traditional uses of petunia, its biology and the nature of genetic modification, the extent of their availability illustrate the limitations of GM regulation system in EU and the rest of the world. However, there is no indication that the GM petunia case would represent a widespread breach of GM regulation, especially with regards to crop plants (Servick, 2017).

2.6. GM seed from the third countries

Cultivation of GM plants and import of GM food and feed are covered by strict regulatory rules in the EU and enforcement of these rules is subject to continuous monitoring from the government and non-government organizations. Consequently, considerable amount of information is available on GM plants imported for food and feed, as well as on viable seeds import. However, much less information is available on GM plant cultivation and food/feed import in the countries neighboring the EU. In contrast to majority of third countries, where situation with cultivation of GMOs is well documented (ISAAA, 2017), information on some other countries, such as Russian Federation and China is much more scarce. This is partly because these countries have their own biotechnology programs resulting in somewhat different GM traits and crop varieties. A report on biotechnology development in China suggested that by 2014, in total, seven GM crops involving ten events were approved for commercial planting (all except MON531 cotton were developed in China), while five GM crops with a total of 37 events were approved for import as processing material. However, at that time only insect-resistant Bt cotton and disease-resistant papaya were commercially planted on a large scale, while petunia, sweet peeper, tomato, rice and maize events, which were approved for cultivation, were not commercialized, and, at least in some cases, authorizations had expired (Li et al., 2014). In response to cases of GM contaminated rice products from China, EC carried out an audit in 2015 on control systems in China for GM food and feed exported to the EU, which concluded that only GM cotton and papaya were commercially cultivated in China. GM rice was not commercially cultivated, although field trials were reported, and cases of seed contamination were identified (DG(SANTE), 2015). Thus, potential contamination of maize, soybean or oilseed rape seeds, in case those were exported from China to the EU, is rather unlikely.

Overview of GMO regulation in the Russian Federation (RF) is provided in recent reviews (Tyshko and Sadykova, 2016; Tsatsakis et al., 2017). GMO cultivation is clearly prohibited in the RF; however, GMOs and products containing GMOs may be imported into the RF for food and feed purposes after a thorough risk assessment (Tyshko and Sadykova, 2016). Whether some of these GMOs and products can be re-exported to EU, and whether they would be labelled as GMOs is not clear. Moreover, in addition to GMO varieties commercialized by predominantly US companies, Russian scientists have developed a number of domestic GM plant varieties,

 https://doi.org/10.1016/j.heliyon.2019.e01242

e.g., Bt toxin-producing insect resistant potato varieties (see the RF patents listed by Korobko et al., 2016) and herbicide tolerant wheat varieties (Miroshnichenko et al., 2007). Transgenic virus resistant sugar beet, as well as GM potatoes resistant to viral and fungal pathogens have also been reported (Skryabin, 2010). At the moment of preparing this review, no reports were found on contaminated seed originating in China or RF. However, it needs to be noted that monitoring of imported seed and food/feed from these countries may be more challenging, because event-specific detection methods may not be readily available. Data from the Border Control Department of the Food and Veterinary Service of Latvia indicated rather significant import of agricultural goods for food and feed purposes during the five-year period 2011−2015, e.g., maize (144 679 t) and oilseed rape (14 469 t) from Russia and maize (1500 t) from Ukraine. The amounts of imported goods tended to vary year on year and likely represent just a fraction of agricultural goods imported to the EU across its Eastern borders.

USDA GAIN report suggested that around 1/3 of the maize grown in Ukraine was genetically engineered (Lefebvre et al., 2014); however, no reliable source of information was provided. Formally, Ukraine does not allow cultivation of GM crops; however, a recent report on state of GMO regulation in Ukraine suggested that most of the cultivated soybean is GM herbicide tolerant, while a significant proportion of cultivated maize is insect resistant (Bashuk, 2017). Publication in Ukrainian agricultural newsletter reported analysis of 1024 maize, wheat, sunflower, soybean, millet, oilseed rape, barley, rye and flax samples of which 120 samples were positive for GM screening elements in real-time PCR analyses performed at the State Research Institute of Laboratory Diagnostics and Veterinary-Sanitary Expertise (Gaidei et al., 2015). Soybean GTS 40-3-2 was detected in 96 out of 111 soybean samples, and maize MON810 was detected in 19 out 429 maize samples collected from six administrative regions in Ukraine. The authors concluded that GM crops were grown and sold in Ukraine (Gaidei et al., 2015). Data from the Food and Veterinary Service Border Control Department of Latvia indicated that some soybean and oilseed rape feed consignments from Ukraine contained GTS 40-3-2 and GT73 admixture, respectively, which in some cases were declared, while in some cases were over 0.9% labelling threshold, but were not declared (Grantina-Ievina et al., unpublished data). The available information does not allow to establish the origin of these consignments; therefore, it is possible that some of the GM soybean and oilseed rape imported into Ukraine is re-exported to the EU countries or, alternatively, they originate from GM crops grown in Ukraine.

In conclusion, considerable uncertainty exists regarding cultivation of GM crop varieties in the third countries with land border with the EU. Although there is no direct evidence for import of contaminated seed for cultivation, we have detected cases of contaminated feed consignments suggesting that regular monitoring may be necessary.

https://doi.org/10.1016/j.heliyon.2019.e01242

3. Conclusions

Combination of literature search and analysis, information from publicly available databases and other information sources identified the three main possible scenarios of introduction of GM seeds and plant propagating material into the EU:

1. Deliberate or inadvertent release of GM seed for cultivation;
2. Contamination of conventional seed lots with GM seeds;
3. Accidental environmental release of GM grains for food or feed.

The available data indicate that likelihood of these scenarios is low. Moreover, the available research literature, relevant databases and reports from national competent authorities rule out possibility of systematic and widespread use of GM seeds in the EU for cultivation, with the exception of maize MON810 which is legally grown in several EU countries. Additionally, seed and food/feed imports from third countries, particularly those with land borders with the EU represent uncertainty due to different legislation and labelling standards; therefore, rigorous monitoring activities are recommended.

Declarations

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Funding statement

The study was partly funded by the Ministry of Agriculture, Republic of Latvia, Rural Support Service project “Assessment of possible risks of genetically modified seeds and propagating material in territory of Latvia and development of risk management recommendations in accordance with Latvian agro-economic conditions”.

Competing interest statement

NR is a member of the European Food Safety Authority GMO expert panel; however, the views expressed in this publication are his own and do not reflect the view of the EFSA GMO Panel.

Additional information

No additional information is available for this paper.

 https://doi.org/10.1016/j.heliyon.2019.e01242

Acknowledgements

The authors wish to thank the Border Control Department of Food and Veterinary Service of Latvia for information on imported animal feed from the third countries.

References

Açikgöz, N., Abay, C., Açikgöz, N., 2002. Progresses in the Turkish seed industry. J. N. Seeds 4, 155–163.

Aono, M., Wakiyama, S., Nagatsu, M., Kaneko, Y., Nishizawa, T., Nakajima, N., Tamaoki, M., Kubo, A., Saji, H., 2011. Seeds of a possible natural hybrid between herbicide-resistant *Brassica napus* and *Brassica rapa* detected on a riverbank in Japan. GM Crops 2, 201–210.

Bashandy, H., Teeri, T.H., 2017. Genetically engineered orange petunias on the market. Planta 246, 277–280.

Bashuk, V., 2017. Features of the state regulation of the production of genetically modified products in the world and in Ukraine. Balt. J. Econ. Stud. 3, 4–11.

Belter, A., 2016. Long-term monitoring of field trial sites with genetically modified oilseed rape (*Brassica napus* L.) in Saxony-Anhalt, Germany. Fifteen years persistence to date but no spatial dispersion. Genes 7.

Booker, H.M., Lamb, E.G., 2012. Quantification of low-level GM seed presence in Canadian commercial flax stocks. AgBioForum 15, 31–35.

Cantrill, R.C., 2008. International development of methods of analysis for the presence of products of modern biotechnology. Asia Pac. J. Clin. Nutr. 17, 233–236.

Caplan, A., Herrera-Estrella, L., Inze, D., Van, H.E., Van, M.M., Schell, J., Zambryski, P., 1983. Introduction of genetic material into plant cells. Science 222, 815–821.

Cheema, H.M.N., Khan, A.A., Khan, M.I., Aslam, U., Rana, I.A., Khan, I.A., 2016. Assessment of Bt cotton genotypes for the *Cry1Ac* transgene and its expression. J. Agric. Sci. 154, 109–117.

Cooke, R.J., 1999. Modern methods for cultivar verification and the transgenic plant challenge. Seed Sci. Technol. 27, 669–680.

Cowan, T., 2014. Unapproved genetically modified wheat discovered in Oregon: status and implications. Food Saf. Develop. Pol. Programs Res. 3, 105–113.

Cummings, C.H., 2002. Risking corn, risking culture. World Watch 15, 8–19.

 https://doi.org/10.1016/j.heliyon.2019.e01242

Davison, J., Ammann, K., 2017. New GMO regulations for old: determining a new future for EU crop biotechnology. GM Crops Food 8, 13–34.

De Guzman, D., 2004. China signals green light for transgenic oilseeds. Chem. Mark. Rep. 265, 12.

de la Cruz, A., 2016. Spain's GM Maize Production European Seed, p. 3.

Devos, Y., Hails, R.S., Messean, A., Perry, J.N., Squire, G.R., 2012. Feral genetically modified herbicide tolerant oilseed rape from seed import spills: are concerns scientifically justified? Transgenic Res. 21, 1–21.

DG (SANCO), 2011a. Final Report of an Audit Carried Out in Germany from 20 to 29 September 2011 in Order to Evaluate the Official Controls for Genetically Modified Organisms Including Their Deliberate Release into the Environment. DG(SANCO) 2011-8981 – MR FINAL.

DG (SANCO), 2011b. Final Report of an Audit Carried Out in Portugal from 26 to 30 September 2011 in Order to Evaluate the Official Controls for Genetically Modified Organisms Including Their Deliberate Release into the Environment. DG(SANCO) 2011-6260 – MR FINAL.

DG (SANCO), 2011c. Final Report of an Audit Carried Out in Spain from 21 to 30 November 2011 in Order to Evaluate the Official Controls for Genetically Modified Organisms Including Their Deliberate Release into the Environment. DG(SANCO) 2011-8982 – MR FINAL.

DG (SANCO), 2012a. Final Report of an Audit Carried Out in France from 09 to 16 May 2012 in Order to Evaluate the Official Controls for Genetically Modified Organisms Including Their Deliberate Release into the Environment. DG(SANCO) 2012-6318 – MR FINAL.

DG (SANCO), 2012b. Final Report of an Audit Carried Out in the Netherlands from 19 to 23 November 2012 in Order to Evaluate the Official Controls for Genetically Modified Organisms Including Their Deliberate Release into the Environment. DG(SANCO) 2012-6312 – MR FINAL.

DG (SANCO), 2013a. Final Report of an Audit Carried Out in Poland from 22 to 31 January 2013 in Order to Evaluate the Official Controls for Genetically Modified Organisms Including Their Deliberate Release into the Environment. DG(SANCO) 2013-6819 – MR FINAL.

DG (SANCO), 2013b. Final Report of an Audit Carried Out in Slovakia from 10 to 18 September 2013 in Order to Evaluate the Official Controls for Genetically Modified Organisms Including Their Deliberate Release into the Environment. DG(SANCO) 2013-6820 – MR FINAL.

 https://doi.org/10.1016/j.heliyon.2019.e01242

DG (SANTE), 2015. Final Report of an Audit Carried Out in China from 18 November 2015 to 26 November 2015 in Order to Evaluate the Controls Systems for Genetically Modified Organisms in Respect of Food and Feed Intended for Export to the European Union. DG(SANTE) 2015-7640 – MR FINAL.

European Commission, 2016. Commission Staff Working Document. Genetically Modified Commodities in the EU. SWD(2016) 61 final. http://ec.europa.eu/transparency/regdoc/rep/10102/2016/EN/10102-2016-61-EN-F1-1.PDF.

Fernandes, T.J.R., Amaral, J.S., Oliveira, M.B.P.P., Mafra, I., 2014. A survey on genetically modified maize in foods commercialised in Portugal. Food Contr. 35, 338–344.

Fitting, E., 2008. Importing Corn, Exporting Labor: the Neoliberal Corn Regime, GMOs, and the Erosion of Mexican Biodiversity. Food for the Few: Neoliberal Globalism and Biotechnology in Latin America, pp. 135–158. https://doi.org/10.1007/s10460-004-5862-y.

Franzaring, J., Wedlich, K., Fangmeier, A., Eckert, S., Zipperle, J., Krah-Jentgens, I., Hunig, C., Zughart, W., 2016. Exploratory study on the presence of GM oilseed rape near German oil mills. Environ. Sci. Pollut. Res. 23, 23300–23307.

Furst, I., 1999. Swiss soiled seed prompts tolerance question. Nat. Biotechnol. 17, 629–629.

Gaidei, O.S., Zahrebelniy, V.O., Novozhytska, J.N., Usachenko, N.V., Danilchenko, N.L., 2015. Analysis of determining GMOs in cereals in Ukraine 2014 (in Ukrainian). Zernovi Produkti i Kombikormi 57, 25–28.

Gamarra, L.F.R., Delgado, J.A., Villasante, Y.A., Ortiz, R., 2011. Detecting adventitious transgenic events in a maize center of diversity. Electron. J. Biotechnol. 14, 9.

Gerdes, L., Busch, U., Pecoraro, S., 2012. GMOfinder-a GMO screening database. Food Anal. Methods 5, 1368–1376.

Ghosh, P.K., Ramanaiah, T.V., 2000. Indian rules, regulations and procedures for handling transgenic plants. J. Sci. Ind. Res. 59, 114–120.

Goto, H., McPherson, M.A., Comstock, B.A., Stojsin, D., Ohsawa, R., 2017. Likelihood assessment for gene flow of transgenes from imported genetically modified soybean (*Glycine max* (L.) Merr.) to wild soybean (*Glycine soja* Seib. et Zucc.) in Japan as a component of environmental risk assessment. Breed. Sci. 67, 348–356.

 https://doi.org/10.1016/j.heliyon.2019.e01242

Han, S.M., Oh, T.K., Uddin, M.R., Shinogi, Y., Lee, B., Kim, C.G., Park, K.W., 2015. Monitoring the occurrence of genetically modified maize in Korea: a 3-year observations. J. Fac. Agric. Kyushu Univ. 60, 285–290.

Hanzer, R., Ocvirk, D., Špoljarić Marković, S., Fulgosi, H., 2012. Monitoring of GM soybean in high categories of seed on the Croatian seed market. Agric. Conspectus Sci. 77, 127–130.

Hecht, M., Oehen, B., Schulze, J., Brodmann, P., Bagutti, C., 2014. Detection of feral GT73 transgenic oilseed rape (*Brassica napus*) along railway lines on entry routes to oilseed factories in Switzerland. Environ. Sci. Pollut. Res. 21, 1455–1465.

Hileman, B., 2000. At last: a biosafety pact. Chem. Eng. News 78, 65–74.

Hisano, S., Altoé, S., 2008. Brazilian Farmers at a Crossroads: Biotech Industrialization of Agriculture or New Alternatives for Family Farmers? Food for the Few: Neoliberal Globalism and Biotechnology in Latin America, pp. 243–266.

Hochegger, R., Bassani, N., Belter, A., Goerlich, O., Grohmann, L., Kreysa, J., Loose, M., Mazzara, M., Macarthur, R., Perri, E., Rajcevic, B., Rolland, M., Savini, C., Sowa, S., Speck, B., Van Beekvelt, C., Villa, D., 2015. European Network of GMO Laboratories: Working Group “Seed Testing” (WG-ST): Working Group Report. JRC, p. 48.

Horak, M.J., Rosenbaum, E.W., Phillips, S.L., Kendrick, D.L., Carson, D., Clark, P.L., Nickson, T.E., 2015. Characterization of the ecological interactions of Roundup Ready 2 Yield® soybean, MON 89788, for use in ecological risk assessment. GM Crops Food 6, 167–182.

ISAAA, 2016. Global Status of Commercialized Biotech/GM Crops: 2016. ISAAA, Ithaca, NY.

ISAAA, 2017. Global Status of Commercialized Biotech/GM Crops in 2017: Biotech Crop Adoption Surges as Economic Benefits Accumulate in 22 Years. ISAAA, Ithaca, NY.

Kamthan, A., Chaudhuri, A., Kamthan, M., Datta, A., 2016. Genetically modified (GM) crops: milestones and new advances in crop improvement. Theor. Appl. Genet. 129, 1639–1655.

Kawata, M., Murakami, K., Ishikawa, T., 2009. Dispersal and persistence of genetically modified oilseed rape around Japanese harbors. Environ. Sci. Pollut. Res. 16, 120–126.

Kim, C.G., Yi, H., Park, S., Ji, E.Y., Do, Y.K., Dae, I.K., Lee, K.H., Taek, C.L., In, S.P., Won, K.Y., Jeong, S.C., Hwan, M.K., 2006. Monitoring the occurrence

 https://doi.org/10.1016/j.heliyon.2019.e01242

of genetically modified soybean and maize around cultivated fields and at a grain receiving port in Korea. J. Plant Biol. 49, 218–223.

Kimani, V., Gruère, G., 2010. Implications of import regulations and information requirements under the Cartagena protocol on biosafety for GM commodities in Kenya. AgBioForum 13, 222–241.

Kleter, G.A., Prandini, A., Filippi, L., Marvin, H.J.P., 2009. Identification of potentially emerging food safety issues by analysis of reports published by the European Community's Rapid Alert System for Food and Feed (RASFF) during a four-year period. Food Chem. Toxicol. 47, 932–950.

Korobko, I.V., Georgiev, P.G., Skryabin, K.G., Kirpichnikov, M.P., 2016. GMOs in Russia: research, society and legislation. Acta Nat. 8, 6–13.

Kruger, M., Van Rensburg, J.B.J., Van den Berg, J., 2012. Transgenic Bt maize: farmers' perceptions, refuge compliance and reports of stem borer resistance in South Africa. J. Appl. Entomol. 136, 38–50.

Lamb, E.G., Booker, H.M., 2011. Quantification of low-level genetically modified (GM) seed presence in large seed lots: a case study of GM seed in Canadian flax breeder seed lots. Seed Sci. Res. 21, 315–321.

Lefebvre, L., Polet, Y., Williams, B., 2014. Agricultural Biotechnology Annual. Biotechnology and Other New Production Technologies. USDA GAIN Report. USDA.

Li, Y., Peng, Y., Hallerman, E.M., Wu, K., 2014. Biosafety management and commercial use of genetically modified crops in China. Plant Cell Rep. 33, 565–573.

Macias-De Ia Cerda, C.G., Cantú-Iris, M., Cruz-Requena, M., RodrIguez-Herrera, R., González-Vázquez, V.M., Aguilar-González, C.N., Loyola-Licea, J.C., Contreras-Esquivel, J.C., 2012. Transgenic sequences detected in corn, soybean and cotton grains imported to Mexico. Indian J. Genet. Plant Breed. 72, 38–45.

Macilwain, C., 2005. US launches probe into sales of unapproved transgenic corn. Nature 434, 423–423.

Meyer, P., Heidmann, I., Forkmann, G., Saedler, H., 1987. A new petunia flower colour generated by transformation of a mutant with a maize gene. Nature 330, 677–678.

Milcamps, A., Rabe, S., Cade, R., De Framond, A.J., Henriksson, P., Kramer, V., Lisboa, D., Pastor-Benito, S., Willits, M.G., Lawrence, D., Van Den Eede, G., 2009. Validity assessment of the detection method of maize event

 https://doi.org/10.1016/j.heliyon.2019.e01242

bt10 through investigation of its molecular structure. J. Agric. Food Chem. 57, 3156–3163.

Miroshnichenko, D., Filippov, M., Dolgov, S., 2007. Genetic transformation of Russian wheat cultivars. Biotechnol. Biotechnol. Equip. 21, 399–402.

Mousa, H., 2011. Saudi Arabia: Biotechnology Annual Report. Biotechnology: Global Policies, Perspectives and Issues, pp. 483–488.

Mulvaney, D., Krupnik, T.J., 2014. Zero-tolerance for genetic pollution: rice farming, pharm rice, and the risks of coexistence in California. Food Policy 45, 125–131.

Nikolic, Z., Vujakovic, M., Jeromelac, A.M., Jovicic, D., 2010. Implementation of monitoring for genetically modified rapeseed in Serbia. Electron. J. Biotechnol. 13, 17–18.

Nishizawa, T., Nakajima, N., Aono, M., Tamaoki, M., Da Kubo, A., Saji, H., 2009. Monitoring the occurrence of genetically modified oilseed rape growing along a Japanese roadside: 3-year observations. Environ. Biosaf. Res. 8, 33–44.

Nishizawa, T., Nakajima, N., Tamaoki, M., Aono, M., Kubo, A., Saji, H., 2016. Fixed-route monitoring and a comparative study of the occurrence of herbicide-resistant oilseed rape (*Brassica napus* L.) along a Japanese roadside. GM Crops Food 7, 20–37.

Nishizawa, T., Tamaoki, M., Aono, M., Kubo, A., Saji, H., Nakajima, N., 2010. Rapeseed species and environmental concerns related to loss of seeds of genetically modified oilseed rape in Japan. GM Crops 1, 143–156.

Otiman, I.P., Badea, E.M., Buzdugan, L., 2008. Roundup Ready soybean, a Romanian story. Bull. Univ. Agric. Sci. Vet. Med. Cluj-Napoca Anim. Sci. Biotechnol. 65.

Oud, J.S.N., Schneiders, H., Kool, A.J., van Grinsven, M.Q.J.M., 1995. Breeding of transgenic orange *Petunia hybrida* varieties. Euphytica 84, 175–181.

Pandolfo, C.E., Presotto, A., Carbonell, F.T., Ureta, S., Poverene, M., Cantamutto, M., 2016. Transgenic glyphosate-resistant oilseed rape (*Brassica napus*) as an invasive weed in Argentina: detection, characterization, and control alternatives. Environ. Sci. Pollut. Res. 23, 24081–24091.

Park, K.W., Lee, B., Kim, C.G., Kim, D.Y., Park, J.Y., Ko, E.M., Jeong, S.C., Choi, K.H., Yoon, W.K., Kim, H.M., 2010. Monitoring the occurrence of genetically modified maize at a grain receiving port and along transportation routes in the Republic of Korea. Food Contr. 21, 456–461.

 https://doi.org/10.1016/j.heliyon.2019.e01242

Pascher, K., Hainz-Renetzeder, C., Gollmann, G., Schneeweiss, G.M., 2017. Spillage of viable seeds of oilseed rape along transportation routes: ecological risk assessment and perspectives on management efforts. Front. Ecol. Evol. 5, 104.

Price, B., Cotter, J., 2014. The GM Contamination Register: a review of recorded contamination incidents associated with genetically modified organisms (GMOs), 1997−2013. Int. J. Food Contam. 1, 5.

Putnam, D.H., Woodward, T., Reisen, P., Orloff, S., 2016. Coexistence and market assurance for production of non-genetically engineered alfalfa hay and forage in a biotech era. Crop Forage Turfgrass Manag. 2.

Ryan, C.D., Smyth, S.J., 2012. Economic implications of low-level presence in a zero-tolerance European import market: the case of Canadian triffid flax. AgBioForum 15, 21−30.

Roberts, A., Finardi-Filho, F., Hegde, S., Kiekebusch, J., Klimpel, G., Krieger, M., Lema, M.A., Macdonald, P., Nari, C., Rubinstein, C., Slutsky, B., Vicien, C., 2015. Proposed criteria for identifying GE crop plants that pose a low or negligible risk to the environment under conditions of low-level presence in seed. Transgenic Res. 24, 783−790.

Rola, A.C., Chupungco, A.R., Elazegui, D.D., Tagarino, R.N., Nguyen, M.R., Solsoloy, A.D., 2010. Consequences of bt cotton technology importation. Philippine Agric. Sci. 93, 9−21.

Sajjad, A.M., Bashir, T., Saeed, S., Ahmad, E., 2016. Detection and copy number estimation of the transgenic nucleotide sequences in an unknown GM event of *Oryza sativa*. Acta Mycol. 69, 1684.

Sanchez, M.A., Leon, G., 2016. Status of market, regulation and research of genetically modified crops in Chile. New Biotechnol. 33, 815−823.

Santa-Maria, M.C., Lajo-Morgan, G., Guardia, L., 2014. Adventitious presence of transgenic events in the maize supply chain in Peru: a case study. Food Contr. 41, 96−101.

Santos, E., Sánchez, E., Hidalgo, L., Chávez, T., Villao, L., Pacheco, R., Navarrete, O., 2016. Status and challenges of genetically modified crops and food in Ecuador. Acta Hortic. 1110, 229−235.

Sarmadi, L., Alemzadeh, A., Ghareyazie, B., 2016. PCR-based detection of genetically modified soybean at a grain receiving port in Iran. J. Agric. Sci. Technol. 18, 805−815.

 https://doi.org/10.1016/j.heliyon.2019.e01242

Schoenenberger, N., D'Andrea, L., 2012. Surveying the occurrence of subspontaneous glyphosate-tolerant genetically engineered *Brassica napus* L. (Brassicaceae) along Swiss railways. Environ. Sci. Eur. 24, 23.

Schulze, J., Brodmann, P., Oehen, B., Bagutti, C., 2015. Low level impurities in imported wheat are a likely source of feral transgenic oilseed rape (*Brassica napus* L.) in Switzerland. Environ. Sci. Pollut. Res. 22, 16936–16942.

Schulze, J., Frauenknecht, T., Brodmann, P., Bagutti, C., 2014. Unexpected diversity of feral genetically modified oilseed rape (*Brassica napus* L.) despite a cultivation and import ban in Switzerland. PLoS One 9.

Serratos-Hernandez, J.A., Gomez-Olivares, J.L., Salinas-Arreortua, N., Buendia-Rodriguez, E., Islas-Gutierrez, F., De-Ita, A., 2007. Transgenic proteins in maize in the soil conservation area of Federal District, Mexico. Front. Ecol. Environ. 5, 247–252.

Servick, K., 2017. How the transgenic petunia carnage of 2017 began. Sci. Insid.

Sieradzki, Z., Mazur, M., Krol, B., Kwiatek, K., 2017. Application of molecular biology in the studies towards genetically modified organisms used in feed in Poland. Med. Weter. Vet. Med. Sci. Pract. 73, 299–302.

Singh, M., Randhawa, G., 2016. Transboundary movement of genetically modified organisms in India: current scenario and a decision support system. Food Contr. 68, 20–24.

Skryabin, K., 2010. Do Russia and Eastern Europe need GM plants? New Biotechnol. 27, 593–595.

Tyshko, N.V., Sadykova, E.O., 2016. Regulation of genetically modified food use in the Russian federation. Food Nutr. Sci. 07 (09), 9.

Traynor, P., Komen, J., 2002. Regulating genetically-modified seeds in emerging economies. J. N. Seeds 4, 213–229.

Tsatsakis, A.M., Nawaz, M.A., Kouretas, D., Balias, G., Savolainen, K., Tutelyan, V.A., Golokhvast, K.S., Lee, J.D., Yang, S.H., Chung, G., 2017. Environmental impacts of genetically modified plants: a review. Environ. Res. 156, 818–833.

Tsuda, M., Okuzaki, A., Kaneko, Y., Tabei, Y., 2012. Relationship between hybridization frequency of *Brassica juncea* × *B. napus* and distance from pollen source (*B. napus*) to recipient (*B. juncea*) under field nconditions in Japan. Breed. Sci. 62, 274–281.

Turkec, A., Lucas, S.J., Karlik, E., 2016a. Monitoring the prevalence of genetically modified (GM) soybean in Turkish food and feed products. Food Contr. 59, 766–772.

 https://doi.org/10.1016/j.heliyon.2019.e01242

Turkec, A., Lucas, S.J., Karlik, E., 2016b. Monitoring the prevalence of genetically modified maize in commercial animal feeds and food products in Turkey. J. Sci. Food Agric. 96, 3173–3179.

Viljoen, C., Chetty, L., 2011. A case study of GM maize gene flow in South Africa. Environ. Sci. Eur. 23, 8.

Yamaguchi, H., Sasaki, K., Umetsu, H., Kamada, H., 2003. Two detection methods of genetically modified maize and the state of its import into Japan. Food Contr. 14, 201–206.

Young, L., Hammerlindl, J., Babic, V., McLeod, J., Sharpe, A., Matsalla, C., Bekkaoui, F., Marquess, L., Booker, H.M., 2015. Genetics, structure, and prevalence of FP967 (CDC Triffid) T-DNA in flax. Springerplus 4, 146.

Zafar, Y., 2007. Development of agriculture biotechnology in Pakistan. J. AOAC Int. 90, 1500–1507.

Zaulet, M., Rusu, L., Kevorkian, S., Luca, C., Mihacea, S., Badea, E.M., Costache, M., 2009. Detection and quantification of GMO and sequencing of the DNA amplified products. Rom. Biotechnol. Lett. 14, 4733–4746.

Zdjelar, G., Nikolić, Z., Vasiljević, I., Jovičić, D., Ignjatov, M., Milošević, D., Tamindžić, G., 2014. Detection of genetically modified crops in animal feed in Serbia. Rom. Agric. Res. 31, 95–101.

Zhang, W., Pang, Y., 2009. Impact of IPM and transgenics in the Chinese agriculture. Integr. Pest Manag. 2, 525–553.

 https://doi.org/10.1016/j.heliyon.2019.e01242