Municipal solid waste landfills as a source of mycotoxins contamination in soil

L V Mosina¹, G N Chupakhina², P V Maslennikov², J A Zhandarova¹ and Е A Dovletyarova³

¹ Russian State Agrarian University - Moscow Timiryazev Agricultural Academy, Str. Timiryazevskaya 49, Moscow, 127550, Russian Federation
² Institute of Living Systems, Immanuel Kant Baltic Federal University, Str. Universitetskaya 2, Kaliningrad, 236040, Russian Federation
³ Peoples’ Friendship University of Russia (RUDN University), Str. Miklukho-Maklaya 6, Moscow, 117198, Russia

E-mail: PMaslennikov@kantiana.ru

Abstract. The authors analyse the results of mycological studies of the soil of one of the largest solid waste landfills in the Moscow region - the Salaryevo solid waste landfill. The agroecological and geochemical characteristics of the contaminated soil are explored. The authors studied the phytotoxicity of soil fungi, using Pisum sativum L as an object of analysis. The number of microscopic fungi in the contaminated soil increased 7 times, the phytotoxic fungi of the genus Alternaria, were 1.8 times higher than the reference level. Penicillium decreased by almost 30%. In many soil samples, fungi of the genus Fusarium were found. An increase in the number of fungi of the genus Alternaria had phytotoxic effect: in pea seedlings (Pisum sativum L.), a slower growth of roots and seedlings was observed.

1. Introduction
Human activities generate a massive amount of various domestic and industrial waste. This creates a number of serious environmental problems [1]. In Russia, the current way of waste management, storage and disposal is causing environmental pollution, leading to irrational use of natural resources and heavy economic losses. It is threatening for the health of current and future generations [2]. Every year, the Russian Federation generates about 7 billion tons of waste, of which only 2 billion are utilised (28.6% in 2012). It is particularly disturbing that waste accumulates toxic substances, including carcinogenic ones. The total amount of such waste has reached 1.6 billion tons [2].

A special place amongst the regions known for landfills belongs to Moscow, the largest industrial giant, with many industrial enterprises. According to various estimates, the city generates from 2.5 to 3.5 million tons of MSW and about 6.1 million tons of industrial waste annually with only 10% of MSW and about 59% of industrial waste undergoing recycling [2]. Considering the danger of existing solid waste landfills (there are 59 of them in the Moscow Region, 11 of them are closed, 48 are active) and their area is about 915 hectares, the problem of pollution of the surrounding urban environment is highly relevant. Dumps and landfills are sources of secondary contamination of the adjacent environments: air and soil, surface and groundwater. Over many years, MSW dumps have been releasing environmentally degrading emissions as a result of various biological and chemical transformations, in the form of...
gaseous and liquid compounds [3, 4]. The danger of soil contamination by MSW is determined not only by direct translocation of TM and other pollutants along the food chain into the human body but also by changing the species composition of the microbial population of the soil as a special bioinert body.

A special place amongst the regions known for landfills belongs to Moscow, the largest industrial giant, with many industrial enterprises. According to various estimates, the city generates from 2.5 to 3.5 million tons of MSW and about 6.1 million tons of industrial waste annually with only 10% of MSW and about 59% of industrial waste undergoing recycling [2]. Considering the danger of existing solid waste landfills (there are 59 of them in the Moscow Region, 11 of them are closed, 48 are active) and their area is about 915 hectares, the problem of pollution of the surrounding urban environment is highly relevant. Dumps and landfills are sources of secondary contamination of the adjacent environments: air and soil, surface and groundwater. Over many years, MSW dumps have been releasing environmentally degrading emissions as a result of various biological and chemical transformations, in the form of gaseous and liquid compounds [3, 4]. The danger of soil contamination by MSW is determined not only by direct translocation of TM and other pollutants along the food chain into the human body but also by changing the species composition of the microbial population of the soil as a special bioinert body.

Microbial communities play an important role in the decomposition of soil organic matter, turning it into accessible batteries for decomposers, thereby closing the circulation of organic matter. High concentrations of heavy metals and other toxicants cause various changes in soil microbiological and biochemical characteristics [5]. As a result of anthropogenic pollution, there is a decrease in the total number of species and a narrowing diversity of microorganisms. There is a decrease in the intensity of the main microbiological processes and the activity of soil enzymes. Phytotoxic forms appear. Mycotoxins pose a particular threat. Mycotoxins are poisonous low-molecular-weight secondary fungal metabolites that contaminate various food and food products on a global scale. They have been named as the major environmental hazards due to their perpetual proliferation in food, and subsequent possible lethal effects on people and animals [6, 7]. One of the mycotoxins, aflatoxin B1 (AFB1), has been classified as the most noxious naturally-occurring carcinogen ever known [6, 7].

Of all toxins microbial poisons are the most dangerous. For example, the lethal dose of botulinum toxin type A (BTA), produced by the anaerobic bacterium Clostridium botulinum, is 0.00003 μg / kg. To compare, the lethal dose of the chemical poison potassium cyanide (KCN) is 10,000 mcg/kg. Fusarium, Aspergillus, and Penicillium. Common mycotoxin-producer moulds can synthesize aflatoxins, cyclopiazonic acid, zearalenone, fumonisins B1, patulin, ochratoxin A, scalenic acid D, T-2 toxins, deoxynivalenol, and nivalenol. Mycotoxins have several negative effects, including being carcinogenic, mutagenic, and teratogenic [8, 9]. The severity of soil contamination with mycotoxins increases, on the one hand, due to the rapid spread of microorganisms and their biological properties, and on the other hand, due to the reduction of natural mechanisms of protection and self-purification of soils. It is believed that the formation of mycotoxins is a response of microscopic fungi to various contaminants, one of the sources of which are MSW landfills.

In this regard, it is necessary to study the changes occurring in the microbial component of the soil under the influence of pollutants. Given little information on this issue, the purpose of our work was to study the geochemical, agroecological, mycological and phytotoxic properties of soils of one of the largest solid waste landfills of the Moscow region - the solid waste landfill «Salaryevo».

2. Materials and methods

We analysed the specific metabolic and phytotoxic characteristics of the microbial cenosis of the «Salaryevo» solid waste landfill, one of the largest in the capital metropolis, located in Leninsky district in the south-west of Moscow. Since its opening in the 1960s, it has been actively used for dumping waste from the capital. In the 1990s, it was used for the disposal of construction materials. The landfill covers the area of 59 hectares. Its height reaches 80 m, and the steepness is from 30 to 400. About 15 million tons of waste are buried here. This is the largest dump in the Moscow region. It was closed on April 1, 2007. Since August 2007, the landfill has been under reclamation.

2. Materials and methods

We analysed the specific metabolic and phytotoxic characteristics of the microbial cenosis of the «Salaryevo» solid waste landfill, one of the largest in the capital metropolis, located in Leninsky district in the south-west of Moscow. Since its opening in the 1960s, it has been actively used for dumping waste from the capital. In the 1990s, it was used for the disposal of construction materials. The landfill covers the area of 59 hectares. Its height reaches 80 m, and the steepness is from 30 to 400. About 15 million tons of waste are buried here. This is the largest dump in the Moscow region. It was closed on April 1, 2007. Since August 2007, the landfill has been under reclamation.
The «Salaryevo» landfill is located in the immediate vicinity of the Moscow Ring Road (1.5 km). It is adjacent to agricultural land. The Vnukovo airport is about 8 km to the west. The sampling method used was the envelope sampling, a technique of combining 5-7 subsamples into a single sample for analysis. These samples were taken at 0-10 cm depth. About 300 samples were collected in spring (May) and autumn (September). The reference sample was the one taken in the sod-podzolic soil zone in the suburban area of Moscow metropolis.

Microbiological studies were carried out in dynamics in accordance with the standard methodology [10, 11]. The study examined the quantitative and qualitative composition of aerobic heterotrophic microorganisms: the total number of ammonifying microorganisms, the total number of microorganisms metabolizing mineral nitrogen, the quantitative and qualitative (generic) composition of microscopic fungi. The probability of mycotoxin production was studied using microscopic fungi increasing their number in a contaminated environment. Soil fungi grew on acidified wort agar. Genus identification was based on morphological and cultural characteristics. The microscopy study was used to examine the structure of the mycelium and reproductive organs. The most representative genera were isolated in pure culture and cultured in Becker's aqueous nutrient medium [12] at a temperature of 25-27 degrees for 6 days. The next step was the identification of their phytotoxic effect. For this purpose, after incubation, the fungal biomass was separated from the culture liquid by filtration through sterile cotton. The presence of toxins was determined by the method of phytotesting [10, 11] involving the analysis of the rate of germination of bioindicator's seeds placed in fungal exudates.

The plant indicators were the seeds of garden pea (Pisum sativum). For the purposes of this study, the phytotoxic effect was the reduction in the length of the roots of seedlings and the decrease in the germination energy of the seeds of bioindicators placed in the fungus exudates, expressed as a percentage. The seeds were considered germinated if the seed coat was broken by the seedling. The last seeds used in the research had the germination rate of 90-95%. They were carefully selected according to the parameters of similarity, disinfected with 0.5% solution of potassium permanganate (KMnO₄), washed with sterile tap water and soaked in the exudate of the fungal culture with concentration 4,5.10⁶ CFU/ml for 30 minutes. Then the seeds were placed evenly on wet filter paper in Petri dishes (15 pcs into each) to germinate. The dishes were incubated in a thermostat at 25 degrees with constant moisture level for 5 days. Pea seeds placed in sterile tap water were used as reference. The experiment was replicated four times.

3. Results and discussion

The analysis of the geochemical properties of the soil of the MSW landfill revealed a high level of contamination by pollutants. The upper 10-cm layer of soil was characterized by extremely high density: the volume of the bulk soil of the land grounds of the landfill was about 34% higher than the control sod-podzolic soil (1.64 ± 0.12 g / cm³ and 1.0 ± 0.09 g / cm³, respectively). Along with unfavourable physical properties, the soil of the MSW landfill was characterized by significant contamination with heavy metals: their level exceeded the MPC by a factor of 2-3. The lead content was 56.7 ± 5.2 mg / kg, Cd - 1.1 ± 0.89 mg / kg. A high concentration of oil products was also observed in the soil of the landfill - 1150 ± 116 mg / kg, which is 4 times higher than the MPC. The surfactant content in the soil of the landfill was 1.38 ± 0.12 mg/kg.

Agroecological characteristics of the landfill soil (humus content, acidity, nutrients) are generally characteristic of zonal sod-podzolic soils. According to the humus content (1.49 ± 0.09%), this soil is poor in organic matter and slightly acid. The availability of P₂O₅ (80.48 ± 7.4 mg / kg) and K₂O (32.0 ± 0.09 mg / kg) is, respectively, medium and very low (less than 10 mg / kg). Given the adverse environmental properties of the landfill, it stands to reason to assume that its biological and microbial components are changing, since they are the most sensitive to changes. Thus, it reflects the combination of soil biological and biochemical processes associated with the activity of its fauna, microflora and roots. For this reason, the authors conducted a study of microbiota (table 1.).
Table 1. The dynamic succession of the qualitative composition of aerobic heterotrophic microorganisms (CFU/g dry soil).

| Sample       | Reference | Soil       |
|--------------|-----------|------------|
|              | Ammonifying microorganisms (MPA) (million CFU/g) | Soil Ammonifying microorganisms (MPA) (million CFU/g) |
| May          | 4.3 ± 0.38 | 0.05 ± 0.004 |
| September    | 9.6 ± 0.84 | 0.09 ± 0.08 |
| Total        | 13.9 ± 1.11| 0.14 ± 0.01 |
|              | Microorganisms metabolizing mineral nitrogen (SAA) (million CFU/g) | Soil Microorganisms metabolizing mineral nitrogen (SAA) (million CFU/g) |
| May          | 4.5 ± 0.39 | 0.08 ± 0.07 |
| September    | 12.4 ± 1.1  | 0.12 ± 0.01 |
| Total        | 16.9 ± 1.2  | 0.2 ± 0.016 |
| Amount       | 30.8       | 0.34       |
|              | Fungi (thousand CFU/g) | Soil Fungi (thousand CFU/g) |
| May          | 12.0 ± 1.1  | 1.1 ± 0.08 |
| September    | 17.2 ± 1.4  | 1.4 ± 0.09 |
| Total        | 29.6 ± 2.2  | 2.5 ± 0.18 |

In both study periods (spring, autumn), the number of microorganisms in the soil of the landfill was significantly (approximately 1-2 orders of magnitude) lower than the reference sample. Especially interesting is the ratio of the total number of ammonifying microorganisms (microorganisms per MPA), microorganisms metabolizing mineral nitrogen (microorganisms on SAA) and microscopic fungi, i.e. the structure of microbiota (SMB), especially in terms of microscopic fungi. In the soil of the landfill, the share of fungi in the total number of microorganisms on MPA+SAA is much higher than that in the reference podzolic soil (figure 1).

In the reference soil sample, there is one part of microscopic fungi (CFU 29 thousand/g of soil; 29.6:30.8=0.96) per one part of the total number of microorganisms metabolising organic (MPA) and mineral (SAA) nitrogen (30.8 million CFU). However, in the soil of the landfill, there are more than 7 parts of fungi (CFU 2.5 thousand; 2.5:0.34=7.4) per 1 part of this group of microorganisms (0.34 million CFU/g). The relative amount of fungi population in the landfill soil is about 7 times higher than that in the reference soil sample.

Such a large increase in the proportion of microscopic fungi in these conditions may be an indication of an environmental imbalance alternating their metabolism, allowing this microbial group to survive in increased pollution. The result of this change in metabolism could be the formation of mycotoxins.
This phenomenon has been discussed in literature. There is an opinion that the formation of fungal toxins, the strongest poisons causing severe diseases in humans and farm animals, is a response of microscopic fungi to various contaminants resulting the disappearance of microflora that can inactivate toxic substances or inhibit the development of a producer [13].

In this regard, it was of interest to identify the possibility (probability) of the formation of mycotoxins in the soil of the landfill. For this purpose, the authors inoculated the microbial communities into Petri dishes. The next step was the identification of fungi genera growing in number in the contaminated environment (table 2).

Table 2. The qualitative composition of microscopic fungi under different contaminants.

| Experiment          | Fusarium | Penicillium | Alternaria | Other     |
|---------------------|----------|-------------|------------|-----------|
| Reference sample    | -        | 54 ± 4.1    | 11.4 ± 1.0 | 34.6 ± 2.9|
| Soil of MSW landfill | 23.2 ± 1.9 | 39.4 ± 3.7 | 27.4 ± 2.3 | 10.0 ± 0.8 |

In the reference soil sample, Penicillium spp. make up a significant proportion (54±4.1%) of microscopic fungi, while the content of Alternaria spp. (11.4±1.0) is low and phytotoxic Fusarium spp. are absent. However, in the soil of the landfill, the structure of microscopic fungi is markedly different. The differences include the appearance of Fusarium spp. (23.2 ± 1.9%), an approximately twofold increase in Alternaria spp. (27.4 ± 2.3% comparing to 11.4 ± 1.0%) and a decrease in Penicillium spp. (from 54.4 ± 4.1 to 39.4 ± 3.7%). The increase in Fusarium and Alternaria spp. suggested changes in metabolic processes leading to the release of the substances inhibiting plant growth processes into the soil.

The phytotoxicity of p. Fusarium fungi is a known fact. Members of the genus Fusarium produce a range of chemically different phytotoxic compounds, such as fusaric acid (FA), fumonisins (fumonisin B1, FB1), beauvericin (BEA), enniatin (ENN), moniliformin (MON) and trichothecenes. They possess a variety of biological activities and cause morphological, physiological and metabolic effects including necrosis, chlorosis, growth inhibition, wilting, inhibition of seed germination and effects on calli [13-15].

For this reason, the study has been conducted with the culture of p. Alternaria fungi, as their ability to produce toxic substances, is not well studied. Fungi of the genus Alternaria are ubiquitous microorganisms growing on a wide range of substrates including soil, wallpaper, decaying organic material and, most important from both toxicological and economical aspects, agricultural crops used for human and animal nutrition [16, 17]. Infection of plants with Alternaria is commonly believed to occur and many Alternaria species are well-known plant pathogens responsible for a series of plant diseases, e.g., black rot of tomatoes, black and grey rot of citrus fruits and black point of cereals [18]. However, some Alternaria species are also able to grow at low temperature and are responsible for the postharvest decay of fruits and vegetables even at refrigerated storage or transport. Unrevealing the taxonomy of the genus Alternaria is still a matter of ongoing research. Species differentiation by molecular biology seems to be more promising than the traditional morphologic approach [16, 17].

The number of fungal secondary metabolites with toxic impact, the so-called mycotoxins, isolated from Alternaria fungi has reached at least 70 compounds up to now [19]. They exhibit great structural divergence and are commonly divided into five groups:

- Dibenzo-a-pyrones (e.g., alternariol, AOH; alternariolmonomethylether, AME);
- Tetramic acid derivatives (e.g., tenuazonic acid, TA);
- Perylene quinones (e.g., altertoxins I – III, ATX I – III);
- Specific toxins produced by Alternaria alternata subspecies lycopersici (AAL-toxins);
- Miscellaneous structures (e.g., tentoxin, TEN).
Three strains of fungi from each sample were isolated, next their phytotoxic ability was determined. The plant indicators were carefully graded seeds of one reproduction of garden pea (*Pisum sativum*) (table 3).

**Table 3.** The effect of phytotoxicity of Alternaria fungi on the culture of pea seed under different contaminants.

| Sample               | Environment       | Average root length, mm | Root length reduction % to the reference level |
|----------------------|-------------------|--------------------------|-----------------------------------------------|
| Reference sample     | Water             | 25 ± 2.0                 | 100                                           |
|                      | Fungus            | 26 ± 2.1                 | 104 ± 9.6                                     |
| Experimental sample  | Soil of MSW landfill | 15.5 ± 1.4             | 59.5 ± 4.9                                    |

The exudates of fungi isolated in the reference soil sample produce almost no change in the germination energy of pea seeds. It remains similar to that in the aquatic environment and even slightly higher due to the presence of biologically active substances in these exudates. The seeds of peas placed in the culture liquid of fungi grown on the landfill soil are characterized by weak energy level. This results in the average length of the roots of seedlings about twice shorter than that of the reference sample. It decreases from 104 ± 9.6% in the reference sample to 59.5 ± 4.9% in landfill one.

Another indication of the increase in phytotoxicity of fungi in the landfill soil is the overtime analysis of pea germination energy (table 4). In the exudates of fungi grown in the landfill soil, the growth processes are slowed down and the germination energy significantly decreases. These changes take place from the beginning of the monitoring period (after 18 hours). The number of seeds sprouting in the same period in the reference sample is about 1.5 times higher (17 ± 1.4%) compared to that in the landfill soil (11.1 ± 0.9%). This lag has been observed throughout the monitoring period. By the end of it (after 96 hours), almost all the seeds of the pea culture had sprouted, while the lag in the landfill soil sample by this time was significant (62 ± 2.4%).

**Table 4.** Pea seeds' germination energy under the influence of fungal exudates under different contaminants.

| Sample               | Control time (hour) | 18 ± 2.0 | 24 ± 2.0 | 30 ± 2.0 | 48 ± 2.0 | 96 ± 2.0 |
|----------------------|---------------------|----------|----------|----------|----------|----------|
| Reference sample     |                     | 17 ± 1.4 | 32 ± 2.0 | 64 ± 3.5 | 95 ± 5.3 | 99 ± 7.6 |
| Soil of MSW landfill |                     | 11 ± 0.9 | 14.2 ± 1.0 | 32 ± 2.1 | 43 ± 2.3 | 57 ± 3.8 |

The studies made it possible to establish changes in the mycological composition and in the metabolic processes in the soil of the Salaryevo landfill causing the formation of mycotoxins. This indicates an even greater deterioration of the ecological state of the adjacent territory and adversely affects human health. In this regard, the accumulation of information about microbial metabolites activity will contribute to a deeper understanding of the complex relationships between plants, soil and microorganisms. This will facilitate the development of effective means of combating negative phenomena caused by toxic metabolites of soil microorganisms.

**4. Conclusion**

The geochemical analysis of the soil of the MSW landfill revealed a high level of contamination. The land mass of the landfill was about 34% higher than the reference sod-podzolic soil. The content of heavy metals in the soil exceeded the MPC two to three times. The content of lead was 56.7 ± 5.2 mg / kg, and Cd - 1.1 ± 0.89 mg / kg. The content of oil products exceeded the norm by 4 times. The
concentration of surfactants in the soil of the landfill was $1.38 \pm 0.12$ mg / kg, which also exceeded the reference level.

Agroecological properties of the landfill soil (humus content, acidity, nutrients) are generally characteristic of zonal sod-podzolic soils. According to the humus content ($1.49 \pm 0.09\%$), this soil is poor in organic matter and the degree of acidity is relatively low. The content of $P_2O_5 (80.48 \pm 7.4$ mg / kg) and $K_2O (32.0 \pm 0.09$ mg / kg) is, respectively, medium and very low (less than 10 mg / kg).

Against the background of contamination of the landfill soil with toxic substances, changes in the structure of the soil microbial cenosis were revealed. A significant decrease (several orders of magnitude) in the number of aerobic heterotrophic microorganisms using organic and mineral forms of nitrogen was identified. A 7-fold increase in the number of microscopic fungi was observed in the soil of the landfill compared with the reference level. Among microscopic fungi, the amount of the phytotoxic genus Alternaria increased 1.8 times, and that of the genus Penicillium decreased by about 30%. Fusarium fungi were found in soil samples from the landfill.

We identified an interdependence between the increase in the number of fungi of the genus Alternaria and their phytotoxicity in the seedlings of Pisum sativum, which manifested in a 2-fold decrease in the length of plant roots and a slower growth over time.

Changes in the species composition of the microbial cenosis of the landfill soil under the influence of pollutants are a serious environmental problem since under these conditions the activity of microflora, which can inactivate toxic substances or inhibit the development of mycotoxin producers, decreases. Toxic substances formed during the decomposition of solid waste suppress the natural microflora and stimulate the formation of fungal toxins - strong poisons that cause serious diseases in humans and farm animals.

**Acknowledgments**

This research was supported by the Russian Academic Excellence Project at the Immanuel Kant Baltic Federal University.

**References**

[1] Ojeda-Benítez S, Aguilar-Virgen Q, Taboada-González P and Cruz-Sotelo S E 2013 Household hazardous wastes as a potential source of pollution: A generation study *Waste Management & Research* **31** 1279-84

[2] Trubaev P A, Verevkin O V, Grishko B M, Tarasyuk P N, Schekin I I, Suslov D Yu and Ramazanov R S 2018 Investigation of landfill gas output from municipal solid waste at the polygon *Journal of Physics: Conference Series* **1066** 012015

[3] Wang Y, Pelkonen M and Kaila J 2012 Effects of temperature on the long term behavior of waste degradation, emissions and post-closure management based on landfill simulators *The Open Waste Management Journal* **5** 19-27

[4] Hard M, Gamperling O and Huber-Humer M 2013 Comparison between lab- and full-scale applications of in situ aeration of an old landfill and assessment of long-term emission development after completion *Waste Management* **33**(10) 2061-73

[5] Chupakhina G N, Maslennikov P V, Mosina L V, Skrypnik L N, Dedkov V P, Chupakhina N Yu and Feduraev P V 2017 Accumulation of biogenic metals in the plants of urbanised ecosystems in the city of Kaliningrad *Research Journal of Chemistry and Environment* **21**(1) 9-17

[6] Gbashi S, Madala N E, De Saeger S, De Boeve M and Njobeh P B 2019 Numerical optimization of temperature-time degradation of multiple mycotoxins *Food and Chemical Toxicology* **125** 289-304

[7] Kadakal Ç and Tepe T K 2018 Is ergosterol a new microbiological quality parameter in foods or not? *Food Reviews International* **35**(2) 1-11

[8] Enyiukwu D N, Awurum A N and Nwaneri J A 2014 Mycotoxins in stored agricultural products: Implications to food safety and health and prospects of plant-derived pesticides as novel
approach to their management Greener Journal of Microbiology and Antimicrobials 2 32-48
[9] Zain M E 2011 Impact of mycotoxins on humans and animals Journal of Saudi Chemical Society 15 129-44
[10] Hugoni M, Luis P, Guyonnet J and Haichar F E Z 2018 Plant host habitat and root exudates shape fungal diversity Mycorrhiza 28(5-6) 451-63
[11] Krauss G-J, Solé M, Krauss G, Schlosser D, Wesenberg D and Bärlocher F 2011 Fungi in freshwaters: ecology, physiology and biochemical potential FEMS Microbiology Reviews 35(4) 620-51
[12] Walker G M and White N A 2017 Introduction to fungal physiology Fungi: biology and applications (John Wiley & Sons)
[13] Singh A K and Pandey A K 2019 Selection of mycoherbicidal potential of Fusarium spp. Against a Noxious Weed Parthenium hysterophorus Journal of Research in Weed Science 2(1) 33-42
[14] Oubraim S, Sedra M H and Lazrek H B 2018 Fusaric acid and phytotoxic metabolites produced by Fusarium oxysporum f. sp. albedinis: effects on date palm and their use for resistance screening trial Journal of Materials and Environmental Sciences 9(5) 1418-25
[15] Pusztahelyi T, Holb I J and Pócsi I 2015 Secondary metabolites in fungus-plant interactions Frontiers in Plant Science 6 573
[16] Gotthardt M, Asam S, Gunkel K, Moghaddam A F, Baumann E, Kietz R and Rychlik M 2019 Quantitation of six alternaria toxins in infant foods applying stable isotope labeled standards Frontiers in Microbiology 10 109
[17] Escrivá L, Oueslati S, Font G and Manyes L 2017 Alternaria Mycotoxins in Food and Feed: An Overview Journal of Food Quality 2017 1569748
[18] Logrieco A, Moretti A and Solfrizzo M 2009 Alternaria toxins and plant diseases: an overview of origin, occurrence and risks World Mycotoxin Journal 2 129-40
[19] Arcella D, Eskola M and Gómez Ruiz J A 2016 Dietary exposure assessment to Alternaria toxins in the European population European Food Safety Authority (EFSA) Journal 14 4654