ANALYTICAL REVIEWS

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Review

ALTERNARIA TOXINS AS A RISK FACTOR FOR POPULATION HEALTH

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Alternaria toxins are toxic metabolites of mold fungi of the genus Alternaria, which are widespread in nature. The purpose of the review was to characterize Alternaria toxins most frequently found in food products and posing a real threat to population health: alternariol (AOH) and its monomethyl ether (AME), altenuene (ALT), tentoxin (TEN), and tenuazonic acid (TeA). The existing toxicological data are insufficient to establish a value of provisional tolerable intake of Alternaria toxins. Based on the chemical structure the daily threshold of toxicological concern was determined: TeA and TEN, 1500 ng/kg b.w.; AOH and AME (taking into account their genotoxicity), 2.5 ng/kg b.w. Currently, the content of Alternaria toxins in food products is not regulated at the national or international levels. Liquid chromatography coupled to (tandem) mass spectrometry is the most preferred method of identification and quantification of Alternaria toxins. Research results indicate significant contamination with Alternaria toxins of food raw materials and products of their processing (including cereals and oilseeds crops; vegetables and fruits, spices, and baby food). Processing of raw materials contaminated with Alternaria toxins contributes, as a rule, to reducing their content in the ready-to-eat product, but does not allow for complete elimination of toxins.

Children of the first three years of life are a population group under the greatest exposure to Alternaria toxins. At the same time, an intake of Alternaria toxins with a diet may exceed the threshold of toxicological concern and pose a real threat to health. The data presented in the review characterize Alternaria toxins as a significant risk factor for public health. To manage the corresponding risk, including through hygienic regulation, it is necessary to conduct additional research on the content of priority Alternaria toxins (AOH, AME, TeA, TEN, ALT) in food products, as well as clarify dose-dependent effects of their toxic action in order to minimize any possible adverse effects of Alternaria toxins on population health in the Russian Federation.

***Keywords:** mycotoxins, Alternaria fungi, alternariol, alternariol monomethyl ether, altenuene, tentoxin, tenuazonic acid, food contamination, toxic effect, exposure assessment.*

Mycotoxins as natural contaminants in food products have long been given special attention by experts in food hygiene [1]. Previous studies made it possible to establish hygienic regulations for the content of certain mycotoxins (aflatoxin B1, ochratoxin A, deoxynivalenol, etc) in food products. At present, special attention of researchers is di-

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rected to the study of non-regulated potentially hazardous for human health toxins of mold fungi widespread in nature, in particular, metabolites of fungi of the genus *Alternaria* - *Alternaria* toxins. Despite the fact that data on their producers, structure and toxicity were obtained already in the middle of the XX century, the widespread presence of *Alternaria* toxins has been identified in different types of food raw materials and processed products, including those produced in the Russian Federation, only over the last 20 years. This is primarily due to the improvement of analytical methods for the identification of mycotoxins. It has been found that dietary intake of *Alternaria* toxins may exceed the threshold of toxicological concern, especially for young children.

The purpose of the review was to characterize *Alternaria* toxins most frequently detected in food products and posing a real threat to public health: alternariol (AOH) and its monomethyl ether (AME), altenuene (ALT), tentoxin (TEN), and tenuazonic acid (TeA).

Physical and chemical properties. According to the chemical structure, AOH (CAS № 641-38-3), AME (CAS № 23452-05-3) and ALT (CAS № 29752-43-0) belong to dibenzo-α-pyrones; TeA (CAS № 610-88-8) – to tetramic acid derivatives; TEN (CAS № 28540-82-1) - to cyclic peptides (Figure).

AOH, ALT and TEN are white powders; AME, pale pink powder; TeA, colorless viscous substance. These compounds are well soluble in organic solvents and to a lesser extent in water.

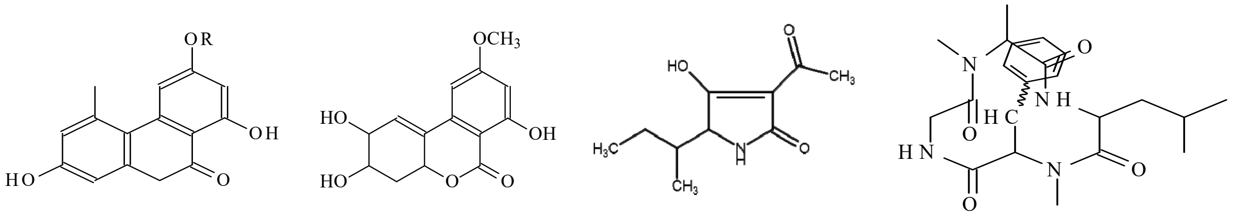
Producing fungi. The main producers of *Alternaria* toxins are microscopic fungi of the genus *Alternaria* (*A. alternata, A. tenuissima, A. solani* etc.), one of the most common components of soil microflora leading to spoilage of agricultural crops, both in the process of ripening, and during transportation and storage [2]. *Alternaria* fungi can infect cereal (wheat, barley, etc.) and oilseed (including sunflower and rapeseed) plants, vegetables (tomatoes, etc.) and fruits (apples, citrus fruits, etc.) [3]. The mold fungi *Epicoccum sorghinum* (former *Phoma sorghina*) are also a significant producer of TeA, affecting cereal crops, especially sorghum, mainly in tropical climate [4]. Under the effect of enzymes secreted by fungi, plant tissues are destroyed at the site of infection with subsequent colonization and synthesis of *Alternaria* toxins [5].

Toxicokinetics. After consumption, TeA is almost completely absorbed by the body. In an experiment, volunteers were given 30 μg TeA in naturally contaminated sorghum-based infant cereals or in tomato juice; 54–81 % of the toxin was detected in their urine after 6 h; 87–93 % after 24 h [6].There are differences in the toxicokinetics described for TeA in different animal species. Thus, absorption (t_{max} = 0.32 h) and excretion ($t_{1/2}$ = 0.55 h) of the toxin after oral administration at a dose of 0.05 mg/kg b.w. was faster in pigs than in broiler chickens (t_{max} = 2.6 h; $t_{1/2}$ = 2.45 h) [7].

AOH has significantly lower bioavailability. When the toxin was administered to mice at doses of 200 and 1000 mg/kg b.w., no more than 9 % was excreted with urine and about 90 % of the initial amount with feces [8].

Toxic effects. The prevailing amount of toxicological data for *Alternaria* toxins has been obtained for AOH, AME and TeA. The most pronounced acute toxicity was identified for TeA ingestion. AOH and AME, which have genotoxic effects [3] by inhibiting DNA topoisomerase and disrupting DNA integrity [9], are of particular concern. *Alternaria* toxins contamination of food products is considered as a possible cause of the high incidence of esophageal cancer in Henan province (China)) [10].

In acute toxicity studies on female mice, intraperitoneal administration of AOH at a dose of 400 mg/kg b.w. resulted in death of



AOH: R=H;
AME: R=CH_3

ALT

TeA

TEN

Figure. The chemical structure of *Alternaria* toxins

3 out of 10 animals; AME (400 mg/kg b.w.), 1 out of 10; ALT (50 mg/kg b.w.), 1 out of 3 animals. No evidence of toxicity was observed in rats when AME, AOH and ALT were fed for 21 days at-levels up to 24, 39 and, 10 mg/kg feed, respectively [3].

Adverse effects on fetal development have been shown for AME (a single intraperitoneal injection into hamsters on day 8 of pregnancy at a dose of 200 mg/kg b.w. (50 and 100 mg/kg b.w., no effect)) and AOH (subcutaneous injections into mice on days 9–12 of pregnancy at a dose of 100 mg/kg b.w.; at a dose of 50 mg/kg b.w., no adverse effects on fetal development were found) [3]. The mechanism of fetotoxic action may be due to the ability of AOH and AME to stimulate estrogen and progesterone production [11].

A phytotoxic effect mediated by inhibition of photophosphorylation has been shown for TEN [12].

TeA has antibacterial and phytotoxic effects, has toxic effects on animals and is considered as a possible cause of endemic disease in humans [3, 10]. The primary mechanism of action of TeA is thought to be inhibition of protein synthesis on ribosomes. In experiments on mice, LD_{50} of TeA equaled 186–225 mg/kg b.w. for males and 81 mg/kg b.w. for females under oral administration; 125–162 mg/kg b.w. and 115 mg/kg b.w. respectively under intravenous administration; 150 mg/kg b.w. for males under intraperitoneal administration and 145 mg/kg b.w. under subcutaneous administration. In rats, the LD_{50} for intravenous administration of the sodium salt was 146 mg/kg b.w. for males and 157 mg/kg b.w. for females; for oral administration, the LD_{50} was 180 mg/kg b.w. and 168 mg/kg b.w., respectively. For day-old chickens, the LD_{50} for oral administration was 37.5 mg/kg b.w. In chicken embryos, the LD_{50} for TeA was 548 µg per egg. Oral administration of TeA to two beagle dogs at a dose of 10 mg/kg b.w. per day (gelatin capsules, 4 separate doses of 2.5 mg/kg b.w.) was accompanied by vomiting and diarrhea and resulted in death of the animals on days 8 and 9. Morphologic examination revealed hemorrhages in the gastrointestinal tract, adrenal *zona fasciculata*, and lungs as well as degenerative changes in the liver. Two monkeys received TeA orally at a daily dose of 22.4 mg/kg b.w. for 3 weeks. Due to lack of adverse effects, the dose was increased to 48.8 mg/kg b.w. from week 4 and to 89.6 mg/kg b.w. from week 5, which resulted in vomiting in the animals. At the same time, in one animal, double injection of TeA at a dose of 89.6 mg/kg b.w. led to bloody diarrhea and subsequent death. Necropsy showed hemorrhagic gastroenteropathy. In 3-week old broiler chickens, TeA in feed (10 mg/kg feed) or by intragastric administration (1.25 and 2.5 mg/kg b.w. per day) for 3 weeks resulted in decreased body weight gain, spleen lesions (enlargement and spotting), and hemorrhage into the intestinal lumen and thigh muscle. No mutagenic effect of TeA was found in a study on bacteria [13]. Precancerous changes were detected in the esophageal mucosa of mice receiving TeA at a daily dose of 25 mg/kg b.w. with drinking water for 10 months [14].

Attention of researchers to TeA is also related to its possible involvement in the development of onyalai (*purpura thrombope-*

nica tropica acuta; acute tropical thrombocytopenic purpura), a severe disease occurring in African countries south of the Sahara Desert [10]. The disease is characterized by fever up to 38–39 °C, chills, pain in the joints, bones, and muscles, abundant petechial rash on the skin of the trunk and extremities, and thrombocytopenia[1]. On the mucous membrane of the oral cavity, nose and tongue, along with petechiae, there are blisters filled with serous bloody fluid. Profuse bleeding from internal organs is possible. The disease is often fatal.

It should be noted that combine ingestion of *Alternaria* toxins may have more pronounced adverse effects on health compared to the toxic effects of individual *Alternaria* toxins [15]. Simultaneous administration of AME and AOH to mice at a dose of 25 mg/kg b.w., had a more pronounced fetotoxic effect relative to the separate exposure to these toxins [3].

Current toxicological data are insufficient to establish the value of provisional tolerable intake of *Alternaria* toxins. The daily threshold of toxicological concern established on the basis of chemical structure for TeA and TEN is 1500 ng/kg b.w.; for AOH and AME (taking into account their genotoxicity), 2.5 ng/kg b.w. [3].

Hygienic regulation. Currently, no national or international regulations have been established for the content of *Alternaria* toxins in food products. At the same time, EU countries have introduced indicative levels for *Alternaria* toxins, exceeding which is a ground for additional investigations to determine the pathways and causes of contamination (Table 1). In Germany (Bavaria), the TeA content in grain-based (sorghum and millet) infant food should not be more than 500 μg/kg [16].

Determination methods. Methods of thin-layer chromatography, immunoassay, gas and liquid chromatography have been developed for the determination of *Alternaria* toxins in food products [3, 17, 18]. Liquid chromatography coupled to tandem mass spectrometry is the most preferred analytical approach given the high selectivity and sensitivity of the method.

Occurrence in food products. Improvement of analytical approaches to identification and quantification of *Alternaria* toxins served in the XXI century as a methodological basis for the systematic study of their content in food raw materials and food products.

Table 1

Indicative levels for *Alternaria* toxins, exceeding which is a ground for additional investigations to determine the pathways and causes of contamination (in EU countries (μg/kg))[2]

Food	AOH	AME	TeA
Processed tomato products	10	5	500
Paprika powder	-	-	10,000
Sesame seeds	30	30	100
Sunflower seeds	30	30	1000
Sunflower oil	10	10	100
Tree nuts	-	-	100
Dried figs	-	-	1000
Cereal based foods for infants and young children	2	2	500

[1] Zadorozhnii B.A., Petrov B.R. Spravochnik po dermatovenerologii [Reference book on dermatovenerology]. Kiev, “Zdorov’ya” Publ., 1996, 476 p. (in Russian).

[2] COMMISSION RECOMMENDATION (EU) 2022/553 of 5 April 2022 on monitoring the presence of *Alternaria* toxins in food. *EFTA*. Available at: https://www.efta.int/eea-lex/32022H0553 (September 17, 2023).

The results of the studies indicate that *Alternaria* toxins are widely spread in food raw materials and processed products including cereals and oil-bearing crops (sunflower and sesame); and oilseeds, vegetables and fruits, nuts, spices and baby food (Table 2). In this case, the detection of several varieties of *Alternaria* toxins in one sample is characteristic.

High AOH content was found in tomato puree (13 % of samples; ≤ 8756 µg/kg) [36], barley grain (≤ 81 %; ≤ 1689 µg/kg) [18], apples (100 %; ≤ 585 µg/kg) [39], sunflower seeds (8 %; ≤ 246 µg/kg) [33], chili pepper powder (80 %; ≤ 153 µg/kg) [20].

Significant AME contamination was found in barley grain (≤ 15 %; ≤ 6812 µg/kg) [18], tomato puree (54 %; ≤ 1734 µg/kg) [36]; sesame seeds (≤ 80 %; ≤ 311 µg/kg) [28], apples (88 %; ≤ 254 µg/kg) [39], sunflower seeds (11 %; ≤ 197 µg/kg) [33].

Table 2

Content of *Alternaria* toxins in food products

Object of research (number of samples)	Detection frequency and content range in contaminated samples (µg/kg)					Source
	AOH	AME	ALT	TEN	TeA	
Food raw materials and processed products of cereals and oilseeds						
Wheat (494)	N/d – 33 %; < LOQ – 102	N/d – 38 %; < LOQ – 59	N/d	N/d – 100 %; < LOQ – 197	57 – 100 %; < LOQ – 92002	[20–25]
Wheat flour (301)	N/d – 37 %; < LOQ – 99	N/d – 91 %; 0.3 – 62	N/d	20 – 97 %; 2.7 – 129	10 - 99 %; < LOQ – 17719	[19, 23, 26–28]
Wheat bran (21)	N/d	N/d	-	-	67 %. < LOQ – 82609	[19]
Rye (28)	N/d – 33 %; 5	N/d - 33 %; < LOQ	-	15 – 66 %; 4 – 34	-	[21, 25]
Bread (119)	N/d – 100 %; 0.4–10	44 – 76 %; 0.2–6.5	-	82 – 100 %; 2.5–32	98 – 100 %; 2 – 46	[26, 29]
Rice (81)	N/d – 8 %; 1.1	N/d – 8 %; 1.5	N/d	N/d	N/d – 83 %; 1.3 –758	[20, 27, 28]
Oat (33)	20 – 100 %; < LOQ – 53	0 – 50 %; < LOQ – 22	N/d	67 – 100 %; 2 – 2160	100 %; 164 –1579	[21, 22, 25]
Barley (199)	N/d – 81 %; < LOQ -1689	N/d – 20 %; 0.4 – 6812	N/d	N/d – 87 %; < LOQ - 38	12 – 100 %; 2.5 – 3678	[18, 20–22, 25, 28, 30]
Millet (71)	15.9 – 50 %; 1 – 3.5	N/d – 4 %; ≤ 3.2	N/d	N/d	50 – 78 %; 186 -788	[20, 27]
Sesame (12)	14 – 80 %; 1.4 – 95	57 – 80 %; 3.1 – 311	14 – 80 %; 1.1–11	N/d	71 – 100 %; 10 – 912	[28]
Sunflower (180)	N/d – 55 %; < LOQ – 246	N/d – 64 %. < LOQ - 197	N/d – 9 %; < LOQ	20 – 91 %; < LOQ – 800	51 – 100 %; < LOQ – 6260	[28, 31–33]
Vegetable oil (19)	47 %; < LOQ – 6	84 %; < LOQ – 14	N/d	47 %; < LOQ – 11	21 %; < LOQ – 15	[31]
Food raw materials and processed fruit and vegetable products						
Tomatoes (67)	N/d – 71 %; < LOQ – 25	N/d – 38 %; < LOQ – 18	N/d	N/d – 26.4 %; < LOQ – 36	N/d – 100 %; < LOQ–4560	[28, 31, 32, 34]
Processed tomato products:						
• dried tomatoes (43)	3 – 33 %; 13 – 22	N/d – 40 %; 1.3 – 42	N/d	N/d – 10 %; 38	13 – 100 %; 6 – 81592	[20, 34, 35]
• concentrate / paste / puree (121)	13 – 85 %; < LOQ – 8756	N/d – 67 %; < LOQ – 1734	N/d – 20 %; 19 – 94	N/d – 37 %; < LOQ –8.9	14 – 100 %; < LOQ –4021	[20, 28, 36–38]

The End of Table 2

Object of research (number of samples)	Detection frequency and content range in contaminated samples (µg/kg)					Source
	AOH	AME	ALT	TEN	TeA	
• sauce / ketchup (118)	N/d – 85 %; < LOQ – 85	N/d – 78 %; N/d – 35	N/d – 32 %; < LOQ – 12	N/d – 21 %; < LOQ – 2.2	85 – 100 %; 5.2 – 887	[20, 28, 32, 35, 37]
• juice (63)	23 – 71 %; < LOQ – 27	N/d – 54 %; < LOQ – 5	N/d – 50 %; < LOQ – 6.1	N/d – 64 %; < LOQ	40 – 100 %; 3.7 – 340	[28, 35, 37]
Apples (24)	N/d – 100 %; < LOQ – 585	N/d – 88 %; 0.1 – 254	N/d – 38 %; 98 – 372	N/d	N/d – 20 %; 5.7	[28, 32, 39]
Pear paste (76)	36 %; < LOQ –32	8 %; < LOQ – 15	N/d	24 %; < LOQ – 74	67 %; < LOQ – 105	[40]
Dried apricots (67)	N/d	N/d – 5 %; 0.5 – 2.1	N/d	N/d – 7 %; 2.7 – 28	38 – 100 %; 10 – 1232	[20, 41, 42]
Dried figs (31)	N/d – 33 %; 0.7 – 106	N/d – 70 %; 1.6 – 34	N/d	N/d	100 %; 25 – 2345	[32, 42, 43]
Dried dates (53)	N/d	N/d	N/d	13.2 %; 1.4 – 11	34 %; 9.6 – 4411	[41]
Raisins (100)	N/d – 7 %; 3.5 – 16	N/d – 19 %; 0.3 – 14	N/d	N/d – 11 %; < LOQ	35 – 50 %; 6.9 – 594	[20, 41–43]
Wine (30)	20 – 93 %; 0.7 – 11	N/d – 93 %; 0.8 – 1.5	N/d	N/d – 71 %; 1.0 – 1.5	60 – 100 %; < LOQ – 60	[32, 44]
Nuts						
Almonds (5)	N/d	N/d	N/d	N/d	N/d	[20]
Hazelnut (3)	67 %; 3.1 – 3.8	33 %; 3.5	N/d	N/d	67 %; 40 и 62	[20]
Pistachios (2)	50 %; 6.4	N/d	N/d	N/d	50 %; 44	[20]
Spices						
Chili pepper (26)	19 – 80 %; 7.4 – 153	14 – 80 %; 10 – 66	N/d – 10 %; 16 – 129	57 – 60 %; 1.9 – 33	100 %; 4510 – 20478	[20, 45]
Paprika (25)	N/d – 88 %; 21 – 121	6 – 75 %; 9 – 74	N/d – 6 %; 16	41 – 100 %; 0.8 – 73	100 %; 7356 – 18856	[20, 45]
Ginger (16)	N/d	25 %; 31 – 56	19 %; 15 – 24	6 %; 2.1	-	[45]
Infant food						
Cereal base:						
• wheat (10)	N/d – 25 %; < LOQ	N/d – 75 %; < LOQ – 0.4	N/d	17 – 75 %; < LOQ – 1.3	N/d – 75 %; < LOQ – 10	[46, 47]
• rice (10)	N/d – 50 %; < LOQ	25 – 100 %; < LOQ – 0.6	N/d	38 – 100 %; < LOQ – 2.2	38 – 100 %; < LOQ – 109	[46, 47]
• oat (8)	N/d	50 – 100 %; < LOQ – 1.1	N/d	67 – 100 %; < LOQ – 1.5	17 – 100 %; < LOQ – 22	[46, 47]
• millet (7)	N/d – 50 %; < LOQ	20 – 100 %; < LOQ – 0.9	N/d	20 – 100 %; 0.3 – 1.0	80 – 100 %; < LOQ – 221	[46, 47]
• spelt (8)	N/d – 67 %; < LOQ – 7.2	N/d – 100 %; < LOQ – 0.3	N/d	60 – 100 %; < LOQ – 1.0	60 – 100 %; < LOQ – 102	[46, 47]
Apple-based (20)	35 %; < LOQ – 14	100 %; 4.4 – 15	N/d	95 %; 4.1 – 92	70 %; 6.5 – 226	[16]

Note: N/d – less than the method detection limit; LOQ – limit of quantification; "-" – not investigated.

Large amounts of ALT were found in apples (38 %; ≤ 372 µg/kg) [39], chili pepper powder (10 %; ≤ 129 µg/kg) [45], tomato puree (≤ 8 %; ≤ 94 µg/kg) [38], ginger powder (19 %; ≤ 24 µg/kg) and paprika (6 %; 16 µg/kg) [45].

Significant TEN contamination was found in oat grain (67 %; ≤ 2160 µg/kg) [25], dried goji berries (63 %; ≤ 1033 µg/kg) [41], sunflower seeds (91 %; ≤ 800 µg/kg) [31], wheat grain and wheat flour (≤ 100 %; ≤ 197 µg/kg) [21, 26], pear paste (24 %; ≤ 74 µg/kg) [40].

High levels of TeA have been found in wheat grain and its milling products (bran, flour) (≤ 100 %; ≤ 92002 µg/kg) [19, 22], dried tomatoes (≤ 100 %; ≤ 81592 µg/kg) [34], chili pepper powder (100 %; ≤ 20478 µg/kg) and paprika (100 %; ≤ 18856 µg/kg) [20], sunflower seeds (51 %; ≤ 6260 µg/kg) [33].

Data on *Alternaria* toxins contamination of infant food have attracted particular attention. AOH (35 %; ≤ 14 µg/kg), AME (100 %; ≤ 15 µg/kg), TEN (95 %; ≤ 92 µg/kg) and TeA (70 %; ≤ 226 µg/kg) were detected in apple-based infant food [16]. The presence of AOH (≤ 67 %; ≤ 7.2 µg/kg), AME (≤ 100 %; ≤ 1.1 µg/kg), TEN (≤ 100 %; ≤ 2.2 µg/kg) and TeA (≤ 100 %; ≤ 221 µg/kg) was found in grain-based infant food [46, 47]. TeA (up to 18 µg/dm^3) was detected in all fennel tea samples [48].

It should be noted that *Alternaria* toxins may be present in food raw materials not only in free but also in a bound state, for example, in the form of glycosides and sulfates (AOH-3-glucoside, AOH-9-glucoside, AOH-3-sulfate and AME-3-sulfate, etc.). When ingested, such “masked” *Alternaria* toxins may be metabolized with their release and toxic effects [37, 49].

Stability of Alternaria toxins during processing of raw materials and storage. The content of AOH and AME in apple juice did not change significantly during 20 days of storage at room temperature or at 80 °C for 20 min [50].

Processing of raw materials contaminated with *Alternaria* toxins usually leads to a reduction in their content in the ready-to-eat product, but does not allow to achieve complete elimination of toxins.

When wheat is milled, a part of *Alternaria* toxins is transferred to bran: AOH, 56–84 %; TeA, 50–66 %; AME, 23–43 % [51].

Heat treatment used in the production of paste for 30 minutes at 80–90 °C had no significant effect on the concentration of AOH; at 100–110 °C, led to a decrease in the toxin content to 56 % of the initial value However, heating was found to have no significant effect on the amount of AME [52]. In another study [3], incubation of *Alternaria* toxins contaminated sunflower flour at 100 °C for 90 min had no effect on the concentration of AOH or AME, but resulted in a reduction of TeA levels to 50 % of the initial level. Under autoclave conditions, increasing temperature (up to 121 °C) and pressure (up to 0.1 MPa) promoted the complete degradation of AME and reduced AOH and TeA content by 75 % and 67 %, respectively. Water in a matrix may have a significant effect on the thermal stability of *Alternaria* toxins at temperatures above 200 °C. No significant degradation of AOH, AME and ALT was observed when contaminated wheat flour to which water was added (1 part flour to two parts water) was heated to 170–230 °C for 60 min [53, 54]. Also practically no changes were detected in dry samples (without water application) at 170 °C but at 230 °C the content of *Alternaria* toxins decreased significantly: AME, by about 50 %; AOH, by 70 %, ALT, by 90 % of the initial level.

Calculated exposure levels for population. As a result of studies conducted in EU countries, it has been shown that the intake of *Alternaria* toxins with diet may exceed the threshold of toxicological concern. Children of the first three years of life were the population category with the highest average daily *Alternaria* toxins exposure: AOH ≤ 271 ng/kg b.w.; AME ≤ 97 ng/kg b.w.; TEN ≤ 33 ng/kg b.w.; TeA ≤ 3603 ng/kg b.w. [55].

The main contribution to the intake of *Alternaria* toxins was made by fruit and tomato products, berries, cereal products and vegetable oil. In the People's Republic of China, the estimated maximum daily intake of mycotoxins with cereal products for children under 3 years of age was 155 ng/kg b.w. for AOH; AME, 36 ng/kg b.w.; and TeA, 3505 ng/kg b.w., mainly due to rice, wheat, and millet products [27].

Conclusion. The data presented in the review indicate quite frequent and significant contamination of food raw materials and food products with *Alternaria* toxins and serve as evidence of their toxic effects *in vitro* and *in vivo*, which characterizes *Alternaria* toxins as a significant risk factor for public health.

To manage the corresponding risk, including through hygienic regulation, it is necessary to conduct additional studies of the content of priority *Alternaria* toxins (AOH, AME, ALT, TEN, TeA) primarily in cereals and oilseeds, tomatoes, fruits and berries, spices and baby food, as well as to clarify the dose-dependent effects of their toxic action in order to minimize adverse effects of *Alternaria* toxins on health of the population of the Russian Federation.

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