Moulds – friends or enemies?

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Summary:

Moulds are common in our habitat and play significant role in the economy and household. The aim of the article is the indication of selected benefits and threats of moulds present in human environment. The main benefits are: antibiotic synthesis (e.g β-lactam antibiotics production), moulds application in food industry (e.g. mouldy cheese production) and industrial biotechnology (e.g. organic acids synthesis). Threats which are related with moulds presence in our environment are diseases of respiratory system, skin as well as allergies and also possibility of food contamination by mycotoxins synthesized by moulds which can cause animal and people poisoning. The main factors which increase exposure of people to adverse effects of moulds are high moisture, inefficient room ventilation and incorrect storage of resources for food production. Taking care of living quarters technical condition and appropriate control of quality and food storage conditions as well as raw materials for its production, we can reduce undesirable moulds effects.

Keywords: antibiotics, fungal infections, organic acids, mycotoxins, moldy cheese

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1. Introduction

Moulds are saprobionts capable of colonizing almost every environment. They are mostly found in the soil, rarely in fresh water and exceptionally in saltwater. High metabolic flexibility and limited need for growth and development, allow them to colonize ecological niches poor in nutrients necessary for the development of other microorganisms, such as: plastics, painted and plastered walls, wood or paper surface (Wiszniewska et al., 2004; Żukiewicz-Sobczak et al., 2012). On the other hand, mould – as chemoorganotrophic organisms – are eager to use rich organic substrates such as remnants of other organisms, as well as processed food or raw materials for its production, and our body. Filamentous fungi are facultative anaerobic organisms, so they grow best on all kinds of surfaces that provide air access, organic carbon sources and essential minerals, although absence of oxygen doesn't destroy the mycelium. High humidity of the substrate and air are the optimum conditions for the growth of these fungi, however many species, such as the xerophyll species of the *Aspergillus* and *Penicillium* genera, can survive under very dry conditions (Wiszniewska et al., 2004).

Fungus systematics is ununiformed and constantly modified according to new data on their phylogeny and kinship collected. According to the taxonomic rank by Schübler et al. (2001), moulds belong to the Fungi, represented by the following types (divisions): *Ascomycota*, *Basidiomycota*, *Glomeromycota* and *Zygomycota*. Many species of mould were previously classified into an artificially formed group – *Fungi imperfecti* or *Deuteromycota*. It is now known that *Fungi imperfecti* are mainly conidia stages, anamorphs of *Ascomycota*, rarely of *Basidiomycota* (Grzywacz 2015). Therefore, in new classifications, the taxon of *Fungi imperfecti* is not classified (Schüβler et al., 2001, Hibbett et al. 2007).

An important aspect to consider for fungi taxonomy is their organs of reproduction. Fungi that reproduce asexually (through mitotic divisions) produce mitospores (e.g. conidia spores). These spores are produced in large quantities, mostly at the tips of the mycelium. Asexual production of spores is often due to the extreme specialization of the fungi, because genetic studies show that they possess genes that regulate sexual reproduction (Muszewska 2014). As a result of the meiosis, fungi produce haploid spores – meiospores, which are a product of sexual processes (e.g. gametogenesis, zygogenesis and somatogamy).

Molds generally reproduce asexually through mitospores (endospores, conidia, arthrospores). *Zygomycota* (e.g. *Mucor, Rhizopus*) produce endospores (endogenous mitospores) in the sporangium. The conidia spores formed exogenously at the tips of conidiophores (aerial hyphae) are often formed in *Ascomycetes* (e.g. *Aspergillus*, *Penicillium*). *Geotrichum candidum* (*Ascomycota*) form single-celled arthrospores (oidia) as a result of fragmentation of the mycelium hyphae. Fungi of the *Glomeromycota* often produce so-called glomoid spores on cylindrical or funnel-like spore-forming hyphae (Schüβler et al., 2001).

Only some mould species reproduce sexually, where they produce meiospores as a result of the meiosis. Because of the way of meiospores formation they are divided into: *Ascomycota*, *Basidiomycota* and *Zygomycota*.

Moulds form a mycelium composed of aseptate hyphae (e.g. *Zygomycota*), or septate hyphae (*Ascomycota*, and *Basidiomycota*). Moulds produce huge amounts of spores that travel long distances in air and water, therefore in extreme cases spore concentrations in contaminated rooms can exceed $1\times10^5/m^3$ of air. These fungi are also capable of producing mycotoxins and antibiotics, thanks to which they can compete with other microorganisms that occupy the same ecological niche (Wiszniewska et al., 2004).

Moulds are, therefore, extremely common saprobions to which we exposed all the time. Looking at the biology of these fungi, one can argue that they greatly affect the environment they occupy and the organisms that coexist with them, including humans. Moulds can affect other organisms directly, growing on them and using them as a source of food or indirectly through spores and metabolites – antibiotics and toxins. On the other hand, the same abilities of moulds metabolism to metabolize various organic compounds can be used in numerous biotechnological processes.

The purpose of this work is to indicate the benefits and risks of the common presence of mould in the human environment and to familiarize the reader with examples of such influence.

2. Positive aspects of the presence of mould in the human environment

People have been using the properties of moulds in their economy for a long time. They have particularly widespread applications in food biotechnology: in blue cheese production (*Penicillium* species) and meats with mould rind (*Penicilium nalgiovense*). The best known oriental foods for which moulds are used are: soy sauce – shoyu, the production of which requires lactic acid bacteria and yeast, but also *Aspergillus oryzae* or *A. soyae* cultures; soybean paste (miso, yang, tao chieo – depending on the country of origin) obtained from steamed soybeans with *A. oryzae* and *Rhizopus oligosporus*; tempech obtained from skimmed soybeans or legumes with *Rhizopus* or *Mucor* moulds. In Africa, fermented foods obtained from cassava (gari) or maize (ogi) that are a significant part of the diet, are produced with the use of bacteria, yeasts and moulds (*Geotrichum*, *Fusarium*, *Penicillium*, *Aspergillus*).

The properties of moulds have been applied in the processes of biotransformation of organic compounds (mainly acids) and enzyme production (lipases, proteases, amylolytic, cellulolytic and pectinolytic enzymes) used in various technological processes – mainly in the food industry. In addition, moulds are of great importance in medicine as a source of antibiotics. These compounds help in effectively fighting bacterial infections which used to be extremely difficult to treat before antibiotics were discovered. Also lovastatin, which is obtained from *Aspergillus terreus* and *Monascus ruber*, has been used in medicine to reduce blood cholesterol concentration.

Moulds are also used as plant protection products (*Beauveria bassiana, B. brongniartii, Entomophthora grylii, Metarrhizium anisopliae, Paecilomyces fumosoroseus, Verticillium lecanii*). Preparations containing spores of these fungi (e.g. Preferal, Boverin, Mycotal) are sprayed over crops mainly for the purpose of eradicating greenhouse pests such as aphids, mites or spider mites (Żakowska and Piotrowska, 2013).

Below you will find some aspects of mould use of in the economy.

2.1. Moulds as a source of antibiotics

Moulds play an important role in medicine as a source of antibiotics. Species from the genus *Penicillium* and *Aspergillus* produce β-lactam antibiotics, among which is the first antibiotic used in medicine, namely benzylpenicillin (penicillin G). It was discovered in Fleming's laboratory in the *Penicillium notatum* and *P. chrysogenum* cultures in 1929. Phenylacetate

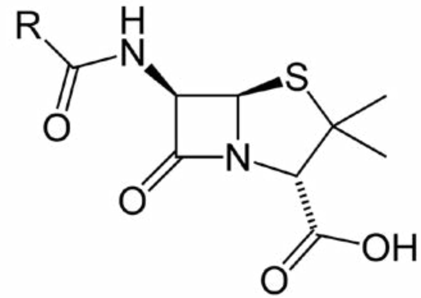

Figure 1. General structural formula of penicillin

Source: Wikimedia Commons.

is added to the medium as a precursor in penicillin G production, while the addition of phenoxyacetate leads to synthesis of penicillin V. The penicillin structure (Figure 1) is based on 6-aminopenicillanic acid, composed of cysteine and valine combined in a double β-lactamotiazolidine ring (Mieszkowski et al., 2011).

Penicillins as well as cephalosporins, cefamycin, carbapenems and monobactams are included in the group of β-lactam antibiotics. All these antibiotics have a β-lactam ring that is linked to another 5- or 6-membered ring (except for monobactams). In addition, each antibiotic in this group has a characteristic side chain (R in Figure 1) which is attached to the β-lactam ring. These antibiotics may also have other side chains, with a cyclic system adjacent to the β-lactam ring. They are highly bactericidal to Gram-positive bacteria (e.g. Staphylococci, Streptococci, *Corynebacterium diphtheriae*) and Gram-negative bacteria (e.g. meningococci, *Treponema pallidum*). The principle of the cytotoxic effect of β-lactam antibiotics is the inhibition of the bacterial cell wall biosynthesis due to glycopeptide transpeptidase deactivation. This prevents the peptidoglycan subunits joining into the final form of the murein polymer. The glycopeptide transpeptidase binds the alanine of one peptidoglycan subunit with the pentaglycine

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bridge of the second peptidoglycan subunit. Penicillin, through the β-lactam ring that is reminiscent of the peptide bond between the alanine residues of the peptidoglycan subunit, is incorporated into the active center of the enzyme causing inhibiting of its activity. The serine residue (OH group) in the active centre of the glycopeptide transpeptidase is bound to the carbonyl group of the penicillin β-lactam ring. The limitation of the murein synthesis inhibits the growth and multiplication of bacteria, resulting in their death (Pałczyński and Jakubowski, 1996; Mieszkowski et al., 2011).

In addition to penicillins and cephalosporins, other antibiotics are also obtained from mould cultures (Chmiel 2013), for example fusidic acid (*Fusidium coccineum*, *Paeciliomyces variotii*), griseofulvin (*Penicillium griseofulvum*), cyclosporin (*Tolypocladium niveum*).

2.2. Use of moulds in cheese production

Moulds play an important role in the production of cheeses with mould growth and overgrowth. Freeze-dried or liquid mould spores are used in the cheese industry to obtain products of exceptional taste and aroma (Kołakowski et al., 2013).

Mould gives cheeses its characteristic (mainly white) look, protects the cheese against spoilage by undesirable mould growth (e.g. *Mucor*), and as a result of the lactic fermentation, it increases the acidity of the cheese. Milk, rennet, salt and micro-organisms are used in the production of blue cheese. The cheese microbiota can be divided into two main groups: starter microbiota (basic and auxiliary) and non-starter microbiota. Moulds along with yeasts, synovial and probiotic microorganisms make up start and auxiliary microbiotics. Spores of noble moulds are most often added to milk in concentrations of about 100 spores per ml of milk (Kolakowski et al., 2013).

The main types of blue cheeses are Camembert and Brie (soft with mould growth), Crescenza and Munster (soft stabilized with mould growth) and Roquefort (with blue mould overgrowth). Different *Penicillium* species (Table 1) are used in the production of these cheeses. Studies conducted on more than 80 cheeses from the Marmara region in Turkey showed over 160 species of moulds in the cheeses studied. The most common were *Penicillium* species (over 50% of cheeses), less common were *Aspergillus* and *Mucor* (15% and 16%, respectively). 16% of the cheeses tested showed the presence of fungi from species other than the listed above (Erdogan et al., 2003). The diversity of moulds cultivated in cheese may indicate the potential for contamination of these products with mycotoxins. In studies conducted on cheeses commercially available in five Turkish cities, more than 50% of tested products contained a dangerous aflatoxin M in concentrations ranging from about 10 to over 700 ng/kg (Ozgoren and Seckin, 2016). By studying the toxin production of *Penicillium roqueforti* strains isolated from blue cheese, it was found that these species produced patulin, penicillinic acid, PR and roquefortin in varying amounts depending on the growth temperature. The fungi produced the least toxins at 5 ° C. With the increase of temperature, the ability to synthesize toxins also rise (Erdogan et al., 2003). The results of the study show that both the selection of mould strains for cheese production and the way they are stored are essential in reducing the risk of mycotoxin contamination of the product. This is of particular importance in view of the global annual production of rennet cheese (that also includes blue cheese) at about 84 million tons, which is a significant contributor to the overall production of dairy products (Cakmakci et al., 2012; et al., 2013; Dysz and Krasnowska, 2013).

Type of cheese	Cheese kind	Mould species
Soft with mould growth	Camembert Brie	*Penicillium camemberti* *Penicillium candidum*
Soft stabilized with mould growth	Crescenza Munster	*Penicillium camemberti* *Penicillium candidum*
With blue mould overgrowth	Roquefort	*Penicillium roqueforti*

Table 1. Selected types of blue cheeses with fungi most commonly used in their production (according to Kołakowski et al., 2013)

2.3. Synthesis of organic acids

Filamentous fungi are capable of producing a variety of organic acids depending on the culture conditions and the organic carbon source used. These include lactic acid, fumaric acid, citric acid, oxalic acid and itaconic acid (Figure 2). Lactic acid is produced by specialized strains of *Rhizopus oryzae* that are capable of producing it in the pentose phosphate pathway, activated by lactic fermentation. In turn, fumaric acid, which is used predominantly in acidification of food and in the production of synthetic resins, is obtained in *Rhizopus nigricaus* cultures (Żakowska and Piotrowska, 2013). The production of citric acid is based on the use of one of three techniques: surface method, submerged method and on solid media. The surface method, which produces citric acid (as the main product) as well as oxalic acid as a by-product of the process (Figure 3), used molasses – a source of glucose, fructose and sucrose. After sterilization, the molasses medium is poured into the fermentation trays and placed in chambers with continuous air circulation and temperature control. When the temperature of the medium falls to 40 ° C, it is inoculated with *Aspergillus niger* spores. After 24 hours of

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incubation, a thin mycelium appears, and its lower layer that adheres to the substrate initiates an intense synthesis of citric acid. This process takes 7-9 days at 30-34 ° C. After changing the culture conditions (pH = 7 and excess phosphorus) *Aspergillus niger* starts to induce the synthesis of oxaloacetal hydrolase, an enzyme that decomposes oxaloacetate to oxalic acid and acetic acid. With low pH and phosphorus deficiency, the main fungal metabolite product is citric acid. The highest yield of citric acid is achieved in the submerged method, which accounts for more than 80% of the world's production of this acid. In this process, unlike the surface method, the mycelium grows in the entire volume of the medium. Citric acid on solid substrates is synthesized from potato, sugar cane, beet pulp and other waste vegetable raw materials. This technology does not require special bioreactors and also *Aspergillus niger* cultures on solid media are able of tolerating high concentrations of metal ions (Żakowska and Piotrowska, 2013). Citric acid is widely used in the food (beverages, dairy products, sweets, jellies, jams, preservatives), metallurgy (metal cleaning), oil (fat and oil production) and pharmaceuticals industries (Soccol et al., 2006). It is worth mentioning that the global annual production of this acid is 1.4 million tons (Musiał and Rymowicz, 2009; Soccol et al., 2006; Swain et al., 2011; Kałuża and Sadowski, 2013).

Oxalic acid in industrial production is chemically synthesized. Currently, work on new routes of oxalic acid producing are carried out because of considerable amount of toxic waste generated as a result of chemical synthesis (Musiał and Rymowicz, 2009). A good example of such research is the attempt to use of rape cake, which is a waste material of oil production, for oxalic acid synthesis by *Aspergillus niger* on solid media. As a result of the experiment it was found, that on starch or sugar substrate *A. niger* mainly produced citric acid, whereas after converting the biotransformation material into rape cake, the fungus synthesized oxalic acid with high efficiency (Gąsiorek et al., 2007). Another method of obtaining oxalic acid, which may be an alternative to chemical synthesis, is the use of sunflower press cake in *A. niger* cultures on solid media. It was found, that when using this raw material, oxalic acid is the only organic acid produced with a maximum yield of about 100 grams per kilogram of medium. In addition, under these conditions, *A. niger* additionally produces significant amounts of cellulo- and xylanolitic enzymes used in various industrial processes (Gąsiorek et al., 2013). The above mentioned examples can be a good way of utilising waste after vegetable oil production to obtain oxalic acid.

Nowadays, itaconic acid also attracts broad interest. The production of this acid is based on cultivating *Aspergillus terreus* or *A. itaconicus* through submerged or surface methods, where glucose or sucrose are used as

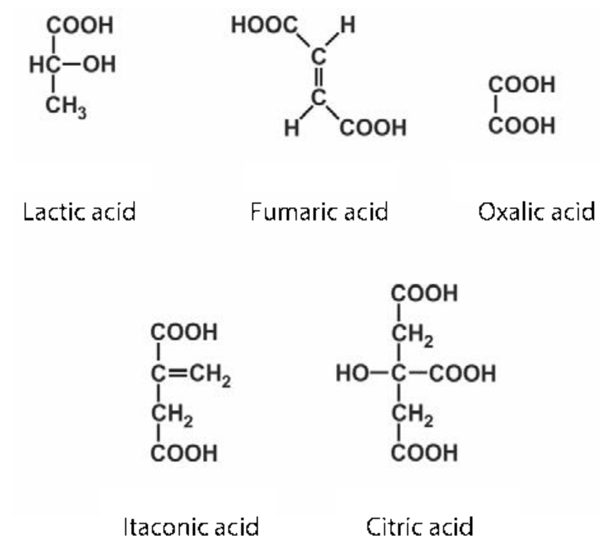

Figure 2. Chemical formulas of selected organic acids synthesized by mould

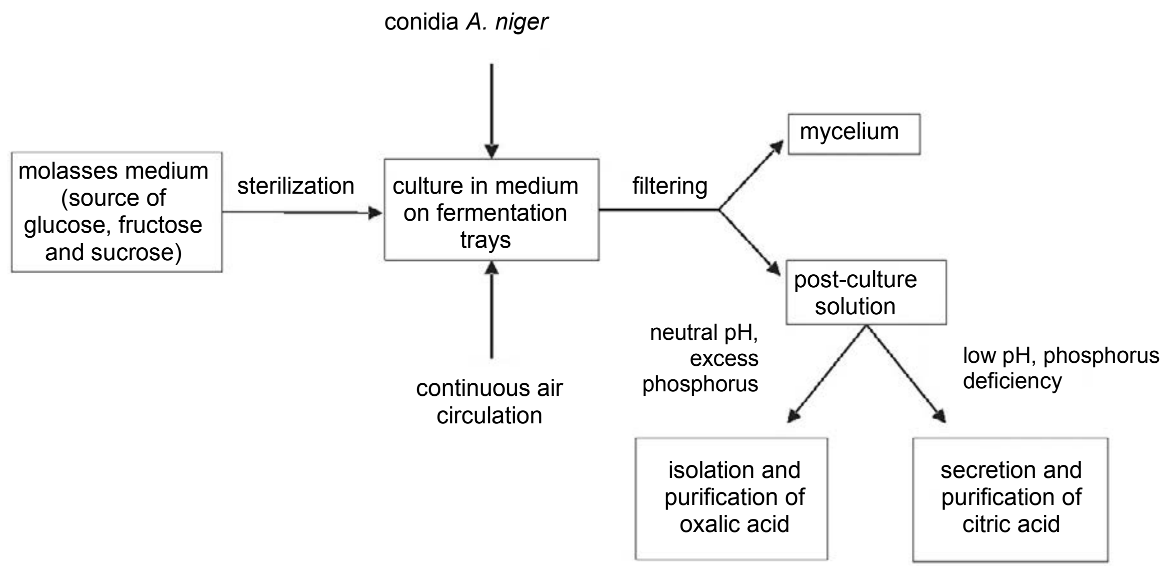

Figure 3. Production of citric acid using Aspergillus niger though surface culture method (Swain et al., 2011)

the carbon source. Itaconic acid, thanks to its ability to polymerize and improve the adhesive properties of various products, is used in industrial resin synthesis, biodegradable hydrophilic polymers, emulsion paints, polyesters, protective coatings and in the textile and paper industries, with an annual production of about 15,000 tons (Musiał, Rymowicz and Kautola, 2009; Żakowska and Piotrowska, 2013). Currently, we are looking for more possibilities in using other types of fungi (e.g. *A. flavus*) and alternative sources of organic carbon (e.g. corn starch hydrolyzate) to improve the yield of itaconic acid production (Wei et al., 2013, Sudarkodi et al. 2012).

3. Negative impact of moulds on human life

Even though, the benefits of using the properties of filamentous fungi are undeniable, one must also be aware of the serious risks to humans and animals from excessive contact with certain species of these organisms and their metabolites. Respiratory and skin problems, as well as poisoning and cancer caused by mycotoxins are particularly dangerous for humans.

3.1. Moulds in residential spaces

The first documented mention of the dangerous effects of fungi on human health, in buildings appeared in the nineteenth century, when the presence of *Penicillium*, *Cladosporium* and *Mucor* genus was confirmed in residential buildings in Copenhagen (cited in Żukiewicz-Sobczak et al., 2012). Structural elements of fungi (spores, hypha) may be the formation focus of the colony. They are considered as an important component of bioaerosols and their concentrations are referred to as colony-forming units (CFUs) per m^3 of air. The presence of moulds in indoor spaces is considered to be an important contamination factor (Wiejak, 2011; Schweer et al., 2016). The following species whose spores can cause harmful health effects, are especially important: *Stachybotrys chartarum*, *Cladosporium sphaerospermum*, *C. cladosporoides*, *C. herbarum* and fungi of the *Aspergillus*, *Penicillium*, *Fusarium*, *Trichoderma* and *Mucor* genera. Spores of these fungi can range from about 3-5 µm (*Aspergillus fumigatus*) to over 20 µm (*Epiccocum nigrum*) and can merge into larger aggregates, settling on different surfaces or remaining in the air (particles up to 5 µm) for a long time, covering significant distances (Mohr, 2002; Stetzenbach et al., 2004; Bonetta et al., 2010). High humidity, along with availability of oxygen and organic substances are the main factors for mould expansion. Excessive moisture, a factor promoting mould growth, is mostly caused by improper ventilation of the premises, lack of adequate insulation of foundations, ceilings and walls, inadequate maintenance of the plumbing system as well as structural defects of the roof covering. In the case of fungi, the outside air is the significant source of room contamination. Particularly highest concentrations of fungal spores are recorded in the summer (1000 to 4000 CFU / m^3), spore numbers in the air are about 10 times lower in spring and winter (Wiejak, 2011). Comparison of indoor and outdoor fungal aerosol concentrations shows that there is even 2 times less spores indoors than outdoors. Different results are obtained by measuring the concentration of bacterial aerosol (Lis et al., 1997). Organic materials such as wood, paints, adhesives and wallpaper which are a reservoir of organic compounds and water, serve as a favourable environment for mould development (Straus, 2009; Żukiewicz-Sobczak et al., 2012). Estimates of air pollution by spores of fungi are presented in Table 2. It should be noted that even in homes without a noticeable mould problem, there is a small concentration of fungal spores (60 CFU / m^3 air), whereas in moulded rooms it can reach a concentration as high as 17,000 CFU / m^3 of air (Pastuszka et al., 2000). Aside from living spaces, the risk associated with the presence of moulds applies to workplaces. Occupational groups particularly exposed to mould spores are office workers, librarians, farmers and food industry workers.

Country	The most common types	Concentration range (CFU / m^3)	
		Residential spaces	Office spaces
Poland	*Aspergillus, Candida, Cladosporium, Penicillium*	60 – 800	18 – 133
Italy	*Cladosporium, Penicillium*	100 – 300	220 – 860 >2000 <500
USA	*Alternaria, Aspergillus, Cladosporium, Penicillium*	1.8 – 2.4 (max. 33)[2]	

Table 2. Comparison of fungi bioaerosol content in living spaces and offices in different countries[1]

[1] – approximate data based on the following publications (Lis et al., 1997; Pastuszka et al., 2000; Sessa et al., 2002; Gooffit-Szymczak and Skowron, 2005; Bonetta et al., 2010)

[2] – data on hospital facilities (Hospenthal, Kwon-Chung and Bennett, 1998)

3.2. Diseases of the respiratory tract and skin caused by mould

The most common illnesses caused by mould include respiratory diseases and surface mycoses. Healthy people, who inhale mould spores should not experience any problems as long as spore concentrations in the air are low. Respiratory organs of healthy people contain self-cleaning mechanisms and adequate immune protection. However, prolonged inhalation of high spore doses (according to Finnish findings, the highest normal fungal aerosol concentration in sparsely populated areas should not exceed 500 CFU/m^3) may represent a serious threat (Reponen et al., 1992). Mould spores can

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cause infectious diseases. Spores can attack the lungs of people with reduced immunity (e.g. AIDS patients or cancer patients) leading to lung colonization and the development of fungal hyphae. Bronchial asthma, allergic rhinitis and bronchial pneumonia are the main respiratory diseases caused by mould (Żukiewicz-Sobczak et al., 2012).

Bronchial asthma is a disease caused by an early type allergic reaction, which involves IgE antibodies, called reagins. The characteristic symptoms of this disease are bronchospasms and asthmatic coughs, most common at rest. The most common cause of this disease among the fungal origin factors, is Alternaria alternata spores (Żukiewicz-Sobczak et al., 2012).

Allergic rhinitis is a disease that causes inflammation of the mucous membranes and conjunctivitis in people with hypersensitivity. Characteristic symptoms are watery secretion, pruritus and sneezing (Wiszniewska et al., 2004).

Hypersensitivity to *Aspergillus fumigatus* can lead to allergic bronchopulmonary aspergillosis. It is an opportunistic infection, and the disease develops in 1-20% of people with asthma. Inhaled spores are not removed from the respiratory tract, resulting in the development of fungal colonies in the bronchial lumen. In infected individuals it causes periorbital pain and chronic bronchitis, what gradually leads to bronchial destruction and pulmonary fibrosis. The illness in its advanced form is difficult to cure and can lead to death. The limited amount of effective medicines is a serious problem in the treatment of aspergillosis. Good results are achieved by intensive amphotericin B treatment which causes the destruction of fungal cell membranes (Wiszniewska et al., 2004; Seyedmousavi et al., 2015).

Superficial mycoses is a separate group of diseases, which are caused by mould. This type of infection mainly occurs on the nail plate and the incidence ranges from a few to 50% of all cases of nail mycosis. Table 3 shows the results of a 3-year mycological studies, which covered 1059 people from Bydgoszcz. Based on the data it can be observed that in 2008 and 2009 more yeast-like fungi were isolated, whereas in 2010 the infections caused by moulds were predominant (Śpiewak, 1997, Kaczmarek and Brzezinski, 2012, Krzyściak and Talaga, 2015). Different species of moulds that belong to the *Aspergillus*, *Scopulariopsis* genera, and to the lesser extend to the *Alternaria* and *Chaetomium* genera were found during diagnosis of nail fungemia. In the course of an infection, the nail plate may stain yellow, yellowish, brownish or white. The disease may develops for a long time asymptomatically and is often recurrent. Untreated mycoses can lead to serious infections, in extreme cases ending with an amputation of the limb (Śpiewak, 1997, Kaczmarek and Brzezinski, 2012).

Pathogen group	Number of patients in each year			
	2008	2009	2010	Total 2008 – 2010
Moulds	128 37,2%	113 36,2%	177 64,8%	418 45%
Yeast fungus	159 46,2%	131 42%	27 9,9%	317 34,1
Dermatophytes	57 16,6%	68 21,8%	69 25,3%	194 20,9
Mould pathogens combined	344	312	273	929

Table 3. Groups of pathogenic fungi isolated from patients in 2008 – 2010 in Bydgoszcz (according to Kaczmarek and Brzezinski, 2012)

3.3. Mycotoxins

Humanity has been in contact with the toxic effects of secondary metabolites of moulds for centuries. An example of mycotoxins (aflatoxin) activity is the massive fall of turkeys on poultry farms in England in 1960. In 1988, In Malaysia, there were 13 deaths following the consumption of pasta contaminated with aflatoxins (Jarzynka et al., 2010). Currently, food contaminated with mould fungus leads to huge economic losses. According to the Food and Agriculture Organization (FAO) estimates, about 25% of the world's cereal grain, or up to 40% according to some estimates, is contaminated with at least one mycotoxin. Fungal metabolites are secreted externally into the medium as exotoxins or are collected in mycelium and conidia as endotoxins. Mycotoxins intake can lead to serious and even lethal poisoning in humans and animals (Jarzynka et al., 2010; Wróbel, 2014; Delgado et al., 2016).

Mycotoxins are poisonous metabolic products of moulds belonging mainly to the *Aspergillus*, *Penicillium*, *Fusarium* and *Stachybotrys* genera. Most are low molecular weight compounds (300 – 600 Da), for which the consumer cannot produce any antibodies. Most mycotoxins are resistant to physical agents. Currently, more than 500 mycotoxins have been chemically characterized, of which more than 20 may be present in food products and threaten the safety of potential consumers. Among them the most significant in food contamination are aflatoxins, ochratoxins, fumonisins and patulin (Grajewski 2006, Figure 4, Table 4).

Aflatoxins are the most poisonous of mycotoxins. They are characterized by teratogenic effects, both in foetal and postnatal development, as well as carcinogenic effects, mainly affecting the liver. Nuts (pistachios, groundnut, Brazil nuts), spices (paprika, nutmeg) and dried fruits are important sources of aflatoxin contamination for humans. The most common aflatoxin is aflatoxin B1, mainly produced by *Aspergillus flavus*. Aflatoxin causes acute toxicity which can be quantified by the LD_{50} parameter. This is the amount of a toxin

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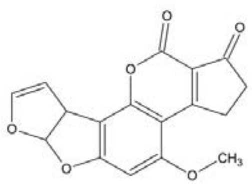
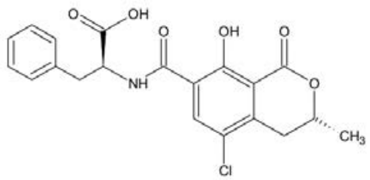
Type of Mycotoxin	Effects of action	Mould species	Source of contamination
Aflatoxins	Mutagenic, teratogenic, cytotoxic, hepatocarcinogenic effects	*Aspergillus flavus Aspergillus parasiticus Aspergillus nomius*	Nuts, spices, dried fruits, dairy products
Ochratoxin A	Nephrotoxic, teratogenic, immunotoxic effects, altered cell cycle dynamics, increased frequency of mutations	*Aspergillus alutaceus Aspergillus niger Aspergillus carbonarius Aspergillus melleus Aspergillus ochraceus Penicillium purpurescens Penicillium commune Penicillium nordicum*	Cereals (mainly maize), animal source foods, wine, coffee, dried fruits, spices
Fumonisin	Neurotoxicity, disturbed lipid metabolism, gene expression modulation, oxidative stress	*Fusarium proliferatum Fusarium subglutinans Fusarium verticillioides*	Cereals, cereal products (mainly rice), beer, sorghum
Patulin	Hepatotoxic, carcinogenic, teratogenic, mutagenic effects	*Penicillium expansum Penicillium griseofulvum Aspergillus chevalieri Aspergillus clavatum Aspergillus terreus Byssochlamys fulva*	Fruit, fruit preserves

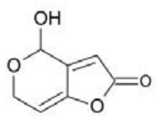
Table 4. Effects of mycotoxins, their source and mould that produce them (Creppy, 2002, Wróbel, 2014)



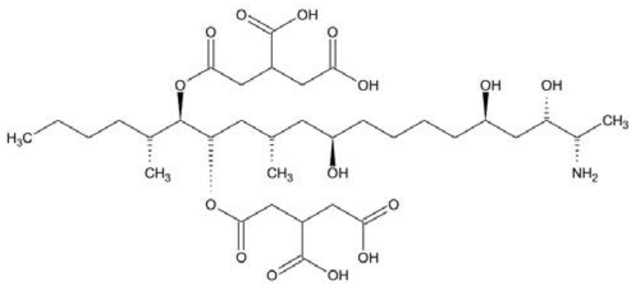
Aflatoxin B1



Ochratoxin A



Patulin



Fumonisin B1

Figure 4. Structural formula of selected mycotoxins

that causes death in half of the population of the tested animals. Table 5 presents the LD_{50} levels of aflatoxin B1 for exeplary lab animals. As indicated by the data, the aflatoxin B1 toxicity depends on the species and the sex of the animal (Serpuk, 2002; Wróbel, 2014).

Species	[1]LD_{50} (mg / kg of body weight)
Domestic rabbit *Oryctolagus cuniculus f. Domesticus*	0.3
Domestic cat *Felis catus*	0.55
Domestic pig *Sus scrofa f. Domestica*	0.62
Domestic sheep *Ovis aries*	1.0
Guinea pig *Cavia porcellus*	1.4
Black rat (male) *Rattus rattus*	7.2
Black rat (female) *Rattus rattus*	17.9

Table 5. Acute toxicity of aflatoxin B1 in relation to selected animals (according to Sechczuk, 2002)

[1] LD_{50} median lethal dose – statistically calculated dose that causes death in 50% of the tested animals.

Ochratoxin A is a typical kind of a nephrotoxin that appears in improperly stored cereal grains, beans, soybeans, dried fruits, wine, coffee and animal source foods. Ochratoxin is mainly produced by species of the *Aspergillus* and *Penicillium* genera. This toxin is present in all climates and is the most common mycotoxin in Poland. It has been shown that 12% of cereals and 2% of feed is contaminated with ochratoxin. Ochratoxins cause irreversible changes in nephrons, as well as neurotoxic, carcinogenic and immunosuppressive effects (Wróbel, 2014).

Fumonisins are mainly found in maize and products made from it. Fumonisin B1, which is produced by *Fusarium proliferatum* and *F. verticillioides*, is especially important in toxicology. These toxins have carcinogenic effects in animals, and possibly also in humans.

Patulin is mainly produced by *Penicillium expansum* and many species of the *Aspergillus* genus. It is usually found in apples and their preserves, but can also be present in other fruits (grapes, peaches, bananas). It is teratogenic, carcinogenic and genotoxic. (Sparrow, 2014).

4. Summary

Mould has the ability to colonize a variety of ecological niches. As saprobionts that decompose organic matter of different origins, they occupy an important place in the global circulation of elements in the environment. Their commonness means that we are constantly exposed to each other. The answer to the question addressed in the tittle of this paper, is neither easy nor clear. Although mould are used extensively in biotechnology, medicine and the food industry, in many cases they have a negative impact on human health, causing serious respiratory and skin diseases. Likewise, toxins synthesized by moulds cause food contamination and consumer poisoning. Important factors that increase the negative exposure to mould in humans and animals are: humidity, lack of adequate ventilation in residential spaces and improper storage and holding of raw materials for food production. In order to limit the negative effects of the presence of mould in the air we breathe, we should prevent mould spores from penetrating into the rooms in which we live and work, maintain adequate humidity and ensure proper ventilation. Reducing the risk of mycotoxins contamination of food and feed can be achieved by controlling the storage conditions of products as well as controlling the quality of the raw material prior to its use in production. Such assessments should in particular refer to the degree of cereal dampness and the presence of mould in the raw fruit used in food industry. Moulds can be our friends or enemies depending on the place and the conditions of their occurrence. By limiting the exposure to the adverse effects of mould, we can use their natural metabolic properties to meet our needs and improve our comfort of life.

References

1. Bonetta SA, Bonetta SI, Mosso S, Sampo S, Carraro E (2010). Assessment of microbiological indor air quality in an Italian office building equipped with an HVAC system. *Environ Monit Assess.* 161: 473-483.
2. Cakmakci S, Cetin B, Gurses M, Dagdemir E, Hayloglu AA (2012). Morphological, Molecular, and Mycotoxigenic Identification of Dominant Filamentous Fungi from Moldy Civil Cheese. *J Food Protect.* 75: 2045–2049.
3. Chmiel A (2013). Mikroorganizmy wykorzystywane w produkcji antybiotyków. W: Libudzisz Z, Kowal K, Żakowska Z (Red.) Mikrobiologia techniczna tom 2. Mikroorganizmy w biotechnologii, ochronie środowiska i produkcji żywności. Wydawnictwo Naukowe PWN, Warszawa.
4. Creppy EE (2002). Update of survey, regulation and toxic effects of mycotoxins in Europe. *Toxicol Lett.* 127: 19-28.
5. Delgado J, Owens RA, Doyle S, Asensio MA, Nunez F (2016). Antifungal proteins from moulds: analytical tools and potential application to dry ripened foods. *Appl Microbiol Biot.* 100: 6991-7000.
6. Dysz K, Krasnowska G (2013). Preferencje konsumentów Polski Południowo –Zachodniej przy wyborze serów podpuszczkowych dojrzewających. *Nauki Inżynierskie i Technologie.* 2: 42-52.
7. Erdogan A, Gurses M, Sert S (2003). Isolation of moulds capable of producing mycotoxins from blue mouldy Tulum cheese produced in Turkey. *Int J Food Microbiol.* 85: 83-85.
8. Gąsiorek E, Fronia J, Firuta P, Podgórski W (2007). Makuch rzepakowy jako substrat do biosyntezy kwasu szczawiowego metodą solid state. *Acta Sci Pol Biotechnologia* 6: 27-32.
9. Gąsiorek E, Walaszczyk E, Podgórski W (2013). Makuch słonecznikowy jako substrat do równoczesnej syntezy kwasu szczawiowego oraz enzymów celulolitycznych i ksylanolitycznych przez Aspergillus niger. *Nauki Inżynierskie i Technologie*. 4: 39-49.
10. Gołofit-Szymczak M, Skowroń J (2005). Zagrożenia mikrobiologiczne w pomieszczeniach biurowych. *Bezpieczeństwo Pracy.* 3: 29-31.
11. Grajewski J (Red.) (2006). Mykotoksyny i grzyby pleśniowe zagrożenia dla człowieka i zwierząt. Wydawnictwo Uniwersytetu Kazimierza Wielkiego, Bydgoszcz.
12. Grzywacz A. (2015). Gatunkowa różnorodność biologiczna grzybów terenów leśnych. *Studia i Materiały CEPL w Rogowie.* 17: 239-253.
13. Hibbett DS, Binder M, Bischoff JF, Blackwell M, Cannon PF, Eriksson OE, Huhndorf S, James T, Kirk PM, Lücking R, Thorsten Lumbsch H, Lutzoni F, Matheny PB, McLaughlin DJ, Powell MJ, Redhead S, Schoch CL, Spatafora JW, Stalpers JA, Vilgalys R, Aime MC , Aptroot A, Bauer R, Begerow D, Benny GL, Castlebury LA, Crous PW, Dai YC, Gams W, Geiser DM, Griffith GW, Gueidan C, Hawksworth DL, Hestmark G, Hosaka K, Humber RA, Hyde KD, Ironside JE, Kõljalg U, Kurtzman CP, Larsson KH, Lichtwardt R, Longcore J, Miadlikowska J, Miller A, Moncalvo JM, Mozley-Standridge S, Oberwinkler F, Parmasto E, Reeb V, Rogers JD, Roux C, Ryvarden L, Sampaio JP, Schüssler A, Sugiyama J, Thorn RG, Tibell L, Untereiner WA, Walker C, Wang Z, Weir A, Weiss M, White MM, Winka K, Yao YJ, Zhang N (2007). A higher level phylogenetic classification of the *Fungi. Mycol Res.* 111: 509–47.
14. Hospenthal D, Kwon-Chung KJ, Bennett JE (1998). Concentrations of airborne Aspergillus compared to the incidence of invasive aspergillosis: lack of correlation. *Med Mycol.* 36: 165-168.
15. Jarzynka S, Dąbkowska M, Netsvyetayeva I, Swoboda – Kopeć E (2010). Mykotoksyny – niebezpieczne metabolity grzybów pleśniowych. *Medycyna Rodzinna.* 4: 113-119.
16. Kaczmarek D, Brzeziński P (2012). Infekcje grzybicze paznokci w rejonie Bydgoszczy w latach 2008 – 2010. *Mikol Lek.* 19: 41-44.
17. Kałuża M, Sadowski Z (2013). Optymalizacja bioprodukcji kwasu cytrynowego w hodowli wgłębnej *Aspergillus niger* prowadzonej w obecności *Tweenu 80. Inż Ap Chem.* 52: 332-333.
18. Kołakowski P, Kowalska M, Sędrowska – Ćwek J (2013). Mikroflora serów dojrzewających. *Innowacyjne Mleczarstwo.* 1: 6-13.
19. Krzyściak P, Talaga K (2015). Pleśnice paznokci. *Twoje zdrowie.* 1: 2-10.
20. Lis DO, Pastuszka JS, Górny RL (1997). Występowanie aerozolu bakteryjnego i grzybowego w mieszkaniach, biurach i środowisku zewnętrznym Górnego Śląska. Wyniki wstępne. *Roczn. PZH.* 48: 59-68.
21. Mieszkowski J, Pałys A, Sobiesiak K, Budzisz E (2011). Biotechnologiczne aspekty syntezy penicylin. *Biotechnologia farmaceutyczna*. 3: 168-175.
22. Mohr AJ (2002). Microorganisms fate and transport. In: Hurst CJ, Crawford RL, Knudsen G, McInerney M, Stetzenbach LD. Washington DC (eds.) Manual of Environmental Microbiology, wyd. 2. ASM Press; pp. 827-838.
23. Musiał I, Rymowicz W (2009). Dobór szczepów *Aspergillus niger*

do biosyntezy kwasu szczawiowego z frakcji glicerynowej. *Inż Ap Chem*. 48: 71-72.
24. Musiał I, Rymowicz W, Kautola H (2009). Wpływ składników podłoża na produkcję kwasu itakonowego przez Aspergillus terreus z glicerolu. *Inż Ap Chem*. 48: 73-74.
25. Muszewska A (2014). Fungal genomes tell a story of ecological adaptations. *Folia Biologica et Oecologica*. 10: 9-17.
26. Ozgoren E, Seckin AK (2016). Aflatoxin M-1 contaminations in mouldy cheese. *Mljekarstvo*. 66: 154-159.
27. Pałczyński C, Jakubowski J (1996). Alergia na antybiotyki beta – laktamowe. *Alergia Astma Immunologia* 1: 76-80.
28. Pastuszka JS, Paw UKT, Lis DO, Wlazło A, Ulfig K (2000). Bacterial and fungal in indor environment in Upper Silesia, Poland. *Atmos Environ*. 34: 3833-3842.
29. Reponen T, Nevalainen A, Jantunen M, Pellikka M, Kalliokoski P (1992). Normal range criteria for indoor air bacteria and fungal spores in subartic climate. *Indoor Air*. 2: 26-31.
30. Schüβler A, Schwarzott D, Walker C (2001). A new fungal phylum, the *Glomeromycota*: phylogeny and evolution. *Mycol Res*. 105: 1413-1421.
31. Schweer KE, Jakob B, Liss B, Christ H, Fischer G, Vehreschild MJGT, Cornely OA, Vehreschild JJ (2016). Domestic Mould exposure and invasive aspergillosis – air sampling of Aspergillus spp. Spores in homes of hematological patients, a pilot study. *Med Mycol*. 54: 576-583.
32. Seńczuk W (2002). Toksykologia. Wydawnictwo Lekarskie PZWL, Warszawa.
33. Sessa R, Di Shiavoni G, Santino I, Altieri A, Pinelli S, Del PM (2002). Microbiological indor air quality in healthy buildings. *New Microbiol*. 25: 51-56.
34. Seyedmousavi S, Guillot J, Arne P, de Hoog GS, Mouton JW, Melchers WJG, Verweij PE (2015). *Aspergillus* and aspergilloses in wild and domestic animals: a global health concern with parallels to human disease. *Med Mycol*. 53: 765-797.
35. Soccol CR, Vandenberghe LPS, Rodrigues C, Pandey A (2006). New Perspectives for Citric Acid Production and Application. *Food Technol Biotech*. 44: 141-149.
36. Stetzenbach LD, Buttner MP, Cruz P (2004). Detection and enumeration of airborne biocontaminants. *Curr Opin Biotech*. 15: 170-174.
37. Straus DC (2009). Molds, mycotoxins, and sick building syndrome. *Toxicol Ind Health*. 25: 617-635.
38. Sudarkodi C, Subha K, Kanimozhi K, Panneerslvam A (2012). Optimization and production of itaconic acid using Aspergillus flavus. *Adv Appl Sci Res*. 3: 1126-1131.
39. Swain MR, Ray RC, Patra JK (2011). Citric Acid: Microbial Production and Applications in Food and Pharmaceutical Industries. *Nova Science Publishers*. 4: 1-22.
40. Śpiewak R (1997). Zakażenia grzybicze skóry i jej przydatków – ważny problem na pograniczu medycyny rodzinnej i dermatologii. *Med Ogólna*. 4: 356-368.
41. Wei L, Wang J, Zhou H, Jin W, Hu Z, Ni J (2013). Directional breeding of high itaconic acid yielding strain of Aspergillus terreus with a new plate technique. *Adv Microbiol*. 3: 376-381.
42. Wiejak A (2011). Ocena stopnia skażenia powietrza zarodnikami grzybów pleśniowych jako istotny czynnik ekspertyzy mikologicznej. *Build Res Instit – Quarterly*. 3: 3-12.
43. Wiszniewska M, Walusiak–Skorupa J, Gutarowska B, Palczyński C (2004). Grzyby pleśniowe w środowisku komunalnym i w miejscu pracy – istotne zagrożenie zdrowotne. *Med Pr*. 55: 257-266.
44. Wróbel B (2014). Zagrożenia zwierząt i ludzi toksynami grzybów pleśniowych zawartych w paszach i żywności. *Woda – Środowisko – Obszary wiejskie*. 3: 159-176.
45. Żakowska Z, Piotrowska M (2013). Grzyby strzępkowe. W: Libudzisz Z, Kowal K, Żakowska Z (Red.) Mikrobiologia techniczna tom 2. Mikroorganizmy w biotechnologii, ochronie środowiska i produkcji żywności. Wydawnictwo Naukowe PWN, Warszawa.
46. Żukiewicz-Sobczak W, Sobczak P, Imbor K, Krasowska E, Zwoliński J, Horoch A, Wojtyła A, Piątek J (2012). Zagrożenia grzybowe w budynkach i w mieszkaniach – wpływ na organizm człowieka. *Medycyna Ogólna i Nauki o Zdrowiu*. 18: 141-146.

