

## Mycotoxin in Medicinal/Aromatic Herbs – a Review

[Micotoxinas en hierbas medicinales y/o aromáticas - Revisión]

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### Abstract

Owing to their conditions of production, and sometimes to poor storage and transportation conditions, herbal products are susceptible to fungal contamination and development. This can lead to the accumulation of mycotoxins in this kind of commodities. Consequently, herbal products can be contaminated with fungal toxins, such as aflatoxins, ochratoxins and other mycotoxins, which pose a serious risk to public health. This paper reviews the main aspects regarding mycotoxin contamination of medical/aromatic herbs, in the context of the importance of this product in a global market. Moreover, the effect of processing on final contamination of derived foods, as well as the analytical methodology commonly employed in fungal and mycotoxin analysis in this type of products was reviewed.

**Keywords:** aromatic herbs, medicinal herbs, mycotoxins, moulds.

### Resumen

Debido a sus condiciones habituales de producción, así como a condiciones inadecuadas de almacenamiento y de transporte, los productos a base de plantas medicinales o aromáticas son susceptibles a la contaminación por mohos, lo que puede conducir a la acumulación de toxinas fúngicas tales como las aflatoxinas, ocratoxinas y otras micotoxinas, lo que supone un grave riesgo para la salud pública. Este artículo revisa los principales aspectos de la contaminación por micotoxinas de las hierbas medicinales y/o aromáticas, teniendo en cuenta el contexto de este producto en un mercado globalizado, así como el efecto del procesado sobre la contaminación final de estos productos. También se revisa la metodología más comúnmente empleada en el análisis de mohos y micotoxinas en este tipo de productos.

**Palabras Clave:** hierbas aromáticas, hierbas medicinales, micotoxinas, mohos.

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**Recibido | Received:** August 14, 2012.

**Aceptado en versión corregida | Accepted in revised form:** November 3, 2012.

**Publicado en línea | Published online:** March 30, 2013

**Declaración de intereses | Declaration of interests:** The authors are grateful to the Spanish (Project AGL2007-66416-C05) and Catalanian (XaRTA- Reference Network on Food Technology) Government for their financial support.

**Este artículo puede ser citado como / This article must be cited as:** L Santos, S Marín, V Sanchis, AJ Ramos. 2013. Mycotoxin in Medicinal/Aromatic Herbs – A Review.

**Bol Latinoam Caribe Plant Med Aromat** 12(2): 119 – 142.

## INTRODUCTION

Occurrence of mycotoxins like aflatoxins (AF), ochratoxin A (OTA), zearalenone (ZEA) and various trichothecenes in herbal products has been reported worldwide. Field production, as well as lack of hygiene and control during raw material storage, processing or distribution of this kind of commodities, can lead to fungal growth and subsequent mycotoxin production. This review aims to address the problem of occurrence of mycotoxigenic species and mycotoxin contamination on aromatic/medicinal herbs. Special emphasis will be placed on microbiota and mycotoxin contamination as well as on analytical methods for mycotoxins in herbs.

### *Herbs: Diversity and Taxonomy*

Medicinal herbs contain some active principles which can have therapeutic applications. All the aromatic plants are medicinal, but not all medicinal herbs are aromatic. Aromatic herbs may be defined as the dried part of the plant such leaf, stem, root, flower, or seed used to impart flavour, odour or colour (DARP, 2002).

The part of the herb to be employed and its presentation depend on the intended use for the herb. In its natural state (fresh or dried) herbs are mainly marketed in herbal stores, but transformed into essential oils, aromas or extracts which are often used in the pharmaceutical, perfume, cosmetic, decor and food industries (DARP, 2002, Moré et al., 2007).

Sometimes literature on medicinal and/or aromatic herbs is confusing because of multiple designations for the same plant depending on the final use. For a given plant it is possible to find several denominations: species name, pharmaceutical name (which changes depending on the part of plant used) and common name (which varies with country, language and usage). Thus the best alternative is to use the species name.

For the reasons mentioned above, in this article we are not going to make distinction between aromatic and medicinal herbs, so the reference to the name of the herbs will be independent of its intended use. Reviewing the overall levels of moulds and mycotoxins contamination that exists in herbs is the aim of this review.

Plants are divided into families in which related plants are grouped together based on the similarity of morphological characteristics. Most of the medicinal and aromatic plants belong to the

following families (Chiej, 1983, Garland, 1989, Teuscher et al., 2005):

- Compositae or Daisy family (e.g., chamomile - *Matricaria chamomile*, true chamomile - *Anthemis nobilis*, marigolds - *Calendula* spp., daisy - *Bellis annua*, wormwood - *Artemisia absinthium*, chicory - *Cichorium intybus* and *C. spinosa*, milk thistle - *Silybum marianum*, silver ragwort - *Senecio bicolor* and artichoke - *Cynara cardunculus*);
- Labiatae or Mint family (e.g., lavanders, mints, thymes, rosemary - *Rosmarinus officinalis*, horehound - *Marrubium vulgare* and balm - *Melissa officinalis*);
- Umbelliferae or Carrot family (e.g., bullwort - *Ammi majus*, wild celery - *Apium graveolens*, wild carrot - *Daucus carota*, sea holly - *Eryngium maritima*, fennel - *Foeniculum vulgare*, anise - *Pimpinella anisum*, wild parsley - *Petroselinium crispum*, hemlock - *Conium maculatum* and alexanders - *Smyrniolum olusatrum*);
- Leguminosae or Pea family (e.g., carob tree - *Ceratonia siliqua*, pea - *Pisum sativum*, white and red clovers - *Trifolium repens* and *T. pratense*, false acacia - *Robinia pseudoacacia*, Judas tree - *Cercis siliquastrum*, alfalfa - *Medicago sativa* and fenugreek - *Trigonella foenum-graecum*);
- Roseaceae or Rose family (e.g., bramble - *Rubus ulmifolius*, rose - *Rosa gallica*, wood strawberry - *Fragaria moschata*, quince - *Cydonia oblongata*, round pear - *Pyrus amygdaliformis*, loquat - *Eriobotrya japonica*, hawthorn - *Crataegus monogyna*, peach, almond and apricot - *Prunus persica*, *P. amygdalus* and *P. armeniaca*);
- Rutaceae or Rue family (e.g., wall and garden rues - *Ruta chalepensis* and *R. graveolens*, rue - *R. montana*, orange - *Citrus aurantium*, bitter orange tree - *Citrus aurantium*, lemon - *Citrus limon*, tangerine - *Citrus paradise*, grapefruit - *Citrus paradisi*);
- Solanaceae or Potato family (e.g., white henbane - *Hyoscyamus albus*, mediterranean withania - *Withania somnifera*, garden thorn apple - *Datura metel*, glaucous tobacco - *Nicotiana glauca* and black nightshade - *Solanum nigrum*);
- Cruciferae or Cress family (e.g., wallflower - *Cheiranthus cheiri*, bitter cress - *Cardamine hirsuta*, shepherd's purse - *Capsella bursa-pastoris*, black mustard - *Brassica nigra*, horseradish - *Armoracia rusticana*, hedge mustard - *Sisymbrium officinale*, white mustard - *Sinapis alba*, wild radish

- *Raphanus raphanistrum*, watercress - *Nasturtium officinale*);
- Liliceae or Lily family (e.g., asphodel - *Asphodelus aestivus*, wild asparagus - *Asparagus aphyllus*, seaside squill - *Drimia maritima*, mediterranean smilax - *Smilax aspera*, greater butcher's broom - *Ruscus hypophyllum*, butcher's broom - *Ruscus aculeatus*, tassel hyacinth - *Muscari comosum*, madonna lily - *Lilium candidum*, bluebell - *Hyacinthus orientalis*, aloe - *Aloe vera*, garlic - *Allium sativum*, garden onion - *Allium cepa*, mediterranean meadow saffron - *Colchium cupani*, meadow saffron - *Colchium autumnale*);
- Caryophyllaceae or Pink family (e.g., sandwort - *Arenaria serpyllifolia*, common chickweed - *Stellaria media*, sand spurrey - *Spergularia rubra*, nail wort - *Paronychia argentea*, smooth rupturewort - *Herniaria glabra*, viscid sandwort - *Alsine tenuifolia*);
- Boraginaceae or Borage family (e.g., borage - *Borago officinalis*, common comfrey - *Symphytum officinale*, purple alkanet - *Anchusa asurea*, yellow gromwell - *Neotostema apulum*, viper's bugloss - *Echium vulgare*, southern hound's tongue - *Cynoglossum creticum*);
- Ranunculaceae or Buttercup family (e.g., pheasant's eye - *Adonis annuus*, lesser celandine - *Ranunculus ficaria*, poppy anemone - *Anemone coronaria*, love in the mist - *Nigella damascena*, short-spurred larkspur - *Delphinium staphysagria*, larkspur - *Delphinium ajacis*, traveller's joy - *Clematis vitalba*, evergreen traveller's joy - *Clematis cirrhosa*);
- Papaveraceae or Poppy family (e.g., greater celandine - *Chelidonium majus*, opium poppy - *Papaver somniferum*, common poppy - *Papaver rhoeas*, sea poppy - *Glaucium flavum*, fumitory - *Fumaria officinalis*, fumitory - *Fumaria capreolata*);
- Malvaceae or Mallow family (e.g., common mallow - *Malva sylvestris*, hairless cotton - *Gossypium herbaceum*, hollyhock - *Althaea rosea*, marsh mallow - *Althaea officinalis*);
- Cucurbitaceae or Cucumber family (e.g., squirting cucumber - *Ecballium elaterium*, pumpkin - *Cucurbita maxima*);
- Verbenaceae or Verbena family (e.g., vervain - *Verbena officinalis*, chaste tree - *Vitex agnus-castus*, cultivated lantana - *Lantana camara*);

- Scrophulariaceae or Figwort family (e.g., snapdragon - *Antirrhinum majus*);
- Phytolaccaceae (e.g., pokeweed - *Phytolacca americana*);
- Euphorbiaceae (e.g., castor bean - *Ricinus communis*).

### The Market of Herbs

Nowadays, the herbs trade enjoys great prosperity worldwide; what began as old agriculture with unselective wild-harvesting of plants, moved into selective collection to extensive cultivated crops. The great prosperity worldwide is mainly due to the opening of new opportunities for manufacturers in new segments such as functional food and cosmetics (Gruenwald, 2008).

Usually, data on herbs market size are included within the general data of the spices market. The EU market is the second largest market for seasonings, spices and herbs in the world, accounting for 1.2 billion euros. Apparent consumption of spices and herbs increased from 321 thousand tonnes in 2004 to 336 thousand tonnes in 2008, indicating moderate average annual growth. The leading consuming EU markets are the UK, Germany, Romania and Hungary, together accounting for 58% (CBI, 2010).

The global herbal market is divided among Germany (28%), Asia (19%), Japan (17%), France (13%), rest of Europe (12%) and North America (11%) (Gruenwald, 2008). The EU market is the largest market for spices and herbs in the world and the most consumed herbs are thyme and oregano (CBI, 2010).

The most commonly grown herbs in the EU countries are: basil, bay leaves, celery leaves, chives, coriander, dill tips, chervil, juniper, marjoram, oregano, parsley, rosemary, sage, savoury, tarragon, thyme and water cress. Despite their low consumption, France, Italy and Greece are important producers of dried herbs (CBI, 2010).

After several years of decline, the total EU imports of herbs and spices increased and reached 988 million euros in 2007; as a result of that, the annual average growth rate was 4%. Leading EU importers of herbs are Germany, the Netherlands, the UK, France and Spain. These countries also share the trait of being the highest importers from developing countries. A large part of the EU export trade consists of spices and herbs which are imported in bulk or in crude form, which are processed and/or repacked,

and then re-exported to other EU and overseas markets. In 2007, the total re-exports of herbs and spices by the EU member countries reached 200 thousand tonnes, representing a value of 616 million euros (CBI, 2010).

On the other hand, in the United States, the herbal dietary supplement market increased in sales in 2010 in comparison to 2009, continuing a steady growth trend since 2003. In 2010, total herb sales reached a turnover of 5,200 million U.S. Dollars, representing a 3.3% increase compared to the previous year. Although the rate of growth is less than the 4.8% growth rate observed from 2008 to 2009, this increase perpetuates the trend of positive growth during 9 of the past 11 years (2000-2010 period) (Blumenthal *et al.*, 2011).

### Microbiota of Herbs

In this kind of commodities production conditions may lead to an increasing risk of microbial contamination. Thus microbial spoilage of the raw herbal material is one of the factors governing the global market of herbs.

Although a large range of microorganisms can be found in herbs, including bacteria, yeasts and moulds, studies concerning microbial contamination are rare.

Some studies showed that aerobic mesophilic bacteria, enterobacteria and coliforms can be detected in herbal samples (García *et al.*, 2001; Guglielminetti *et al.*, 1996; Halt and Klapac, 2005; Kneifel *et al.*,

2002; Tournas *et al.*, 2006). It is possible to find the following bacterial genera: *Bacillus*, *Proteus*, *Staphylococcus*, *Pseudomonas*, *Klebsiella*, *Micrococcus*, *Corynebacterium*, *Streptococcus*, *Enterococcus*, *Alcaligenes*, *Citrobacter* and *Providencia* (Esimone *et al.*, 2002). Although the presence of pathogenic microorganisms is relatively rare, there are some exceptions, such as, *Bacillus cereus*, *Clostridium perfringens*, *Campylobacter jejuni*, *Escherichia coli*, *Escherichia vulneris*, *Enterobacter aerogenes*, *Enterobacter cloacae*, and *Pseudomonas aeruginosa* (Czech, 2001; Esimone *et al.*, 2002; Guglielminetti *et al.*, 1996; Leimbeck, 1987; Martins *et al.*, 2001a). Table N° 1 presents yeast contamination in some herbal samples.

Usually, herbal raw materials are contaminated by different fungal species other than yeast, some of them being mycotoxigenic (Table N° 2). The genus *Aspergillus* is the most frequently found in this kind of commodities (Abe *et al.*, 2008; Abeywickrama and Bean, 1991; Bugno *et al.*, 2006; Chourasia, 1995; Cventinć and Pepeljnjak, 1999; Elshafie *et al.*, 1999; Horie *et al.*, 1979; Roy *et al.*, 1988; Sahay and Prasad, 1990; Singh *et al.*, 2008).

Despite the beneficial effects of herbs, some microorganisms and their metabolites can be found which could lead to serious health problems. Among the microorganisms that may be present, moulds are the most relevant, mainly due to their mycotoxins production capacity.

**Table N° 1**  
**Reported yeast contamination in herbal samples**

Yeast specie	Herbal product	Reference
<i>Aureobasidium</i> spp.	Platycodon	Hitokoto <i>et al.</i> , 1978
<i>Candida guilliermondii</i>	Unavailable data	Martins <i>et al.</i> , 2001a
<i>Candida</i> spp.	Unavailable data	Halt and Klapac, 2005
<i>Cryptococcus albidus</i>	Chamomile, linden	Martins <i>et al.</i> , 2001a
<i>Cryptococcus laurentii</i>	Chamomile, corn silk	Martins <i>et al.</i> , 2001a
<i>Kloeckera japonica</i>	Unavailable data	Martins <i>et al.</i> , 2001a
<i>Rhodotorula glutinis</i>	Chamomile, linden, pennyroyal	Martins <i>et al.</i> , 2001a
<i>Rhodotorula mucilaginosa</i>	Chamomile, garden sage, linden	Martins <i>et al.</i> , 2001a
<i>Rhodotorula rubra</i>	Coriander	Guglielminetti <i>et al.</i> , 1996
<i>Saccharomyces cerevisiae</i>	Unavailable data	Martins <i>et al.</i> , 2001a
<i>Saccharomyces</i> spp.	Unavailable data	Halt and Klapac, 2006
Not identified yeasts	Ginseng supplements	Czech <i>et al.</i> , 2001; Halt and Klapac, 2006; Tournas <i>et al.</i> , 2006

**Table N° 2**  
**Fungal contamination described in herbs.**

Specie name (Common name)	Moulds <sup>(1)</sup>	References
<i>Artemisia absinthium</i> (Wormwood)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Acacia concinna</i> (Shikakai)	<i>A. flavus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>Curvularia</i> spp., <i>F. moniliforme</i> , <i>M.ucedo</i> , <i>P. citrinum</i> , <i>R. stolonifer</i>	Roy and Kumari, 1991
<i>Achyranthes aspera</i> (Prickly-Chaff)	<i>A. flavus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>Fusarium</i> spp., <i>F. moniliforme</i> , <i>Penicillium</i> spp., <i>P. citrinum</i>	Roy and Chourasia, 1990a
<i>Acorus calamus</i> (Sweet Flag)	<i>A. flavus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>Fusarium</i> spp., <i>F. moniliforme</i> , <i>Penicillium</i> spp., <i>P. citrinum</i>	Roy and Chourasia, 1990a
<i>Adhatoda vasica</i> (Malabar Nut)	<i>Abs. corymbifera</i> , <i>Alt. alternata</i> , <i>A. flavus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>C. herbarum</i> , <i>Fusarium</i> spp., <i>F. moniliforme</i> , <i>Mucor</i> spp., <i>Penicillium</i> spp., <i>P. citrinum</i> , <i>Pestalotia</i> spp., <i>T. viride</i> , <i>Umbelopsis</i> spp., other moulds	Abeywickrama and Bean, 1991; Roy and Chourasia, 1990a; Singh et al., 2008
<i>Aerva lanata</i> (Boor)	<i>A. flavus</i> , <i>A. niger</i> , <i>A. wentii</i> , <i>P. janthinellum</i>	Abeywickrama and Bean, 1991
<i>Aframomum melegueta</i> (Grains of Paradise)	<i>Aspergillus</i> spp., <i>Fusarium</i> spp., <i>G. candidum</i> , <i>Penicillium</i> spp., <i>Rhizopus</i> spp.	Efuntoye, 1996
<i>Allium sativum</i> (Garlic)	<i>A. niger</i> , <i>Circinella</i> spp., <i>Cunninghamella</i> spp., <i>Penicillium</i> spp., <i>Rhizopus</i> spp.	García et al., 2001
<i>Aloysia triphylla</i> (Lemon verbena)	<i>A. flavus</i> , <i>A. ochraceus</i>	Rizzo et al., 2004
<i>Alternanthera pungens</i> (Khaki Weed)	<i>A. flavus</i> , <i>A. ochraceus</i> , <i>F. equiseti</i> , <i>F. oxysporum</i> , <i>F. semitectum</i>	Rizzo et al., 2004
<i>Althaea officinalis</i> (Marshmallow)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Alysicarpus vaginalis</i> (Alyce Clover)	<i>A. flavus</i> , <i>A. niger</i> , <i>A. wentii</i> , <i>P. janthinellum</i> , other moulds	Abeywickrama and Bean, 1991
<i>Arctium lappa</i> (Burdock)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Arctostaphylos uva-ursi</i> (Bearberry)	<i>A. flavus</i>	Rizzo et al., 2004
<i>Asparagus racemosus</i> (Asparagus)	<i>Aspergillus</i> spp., <i>A. flavus</i> , <i>A. niger</i> , <i>C. herbarum</i> , <i>Em. nidulans</i> , <i>Fusarium</i> spp., <i>Mucor</i> spp., <i>P. italicum</i> , <i>R. stolonifer</i> , <i>T. viride</i> , other moulds	Chourasia, 1995; Singh et al., 2008
<i>Atractylodes japonica</i> (Japanese Atractylodes)	<i>A. flavus</i> , <i>A. glaucus</i> , <i>A. niger</i> , <i>A. versicolor</i> , <i>Mucor</i> spp., <i>Penicillium</i> spp., <i>Rhizopus</i> spp., other moulds	Hitokoto et al., 1978
(Atractylodes)	<i>A. glaucus</i> , <i>A. niger</i> , <i>Penicillium</i> spp., <i>Rhizopus</i> spp.	Hitokoto et al., 1978
<i>Atropa belladonna</i> (Belladonna)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Azadirachta indica</i> (Neem)	<i>Aspergillus</i> spp., <i>Fusarium</i> spp., <i>Mucor</i> spp., <i>M. fragilis</i> , <i>Penicillium</i> spp., <i>Rhizopus</i> spp., <i>T. viride</i>	Efuntoye, 1996
<i>Baccharis articulata</i>	<i>A. flavus</i> , <i>A. ochraceus</i>	Rizzo et al., 2004

(Birch)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Blepharis edulis</i>	<i>A. flavus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>Chaetomium</i> spp., <i>Curvularia</i> spp., <i>F. moniliforme</i> , <i>M.ucedo</i> , <i>R. stolonifer</i>	Roy and Kumari, 1991
<i>Blepharocalyx tweediei</i>	<i>A. flavus</i>	Rizzo et al., 2004
<i>Peumus boldus</i> (Boldo)	<i>A. ochraceus</i> , <i>F. oxysporum</i>	Rizzo et al., 2004
<i>Caesalpinia digyna</i> (Teri Pods)	<i>A. flavus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>Chaetomium</i> spp., <i>M.ucedo</i> , <i>R. stolonifer</i>	Roy and Kumari, 1991
<i>Calendula officinalis</i> (Marigold)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Camellia sinensis</i> (Black tea)	<i>A. flavus</i> , <i>A. niger</i> , <i>Paecilomyces</i> spp., <i>Penicillium</i> spp.	Elshafie et al., 1999
<i>Capsella bursa-pastoris</i> (Shepherd's Purse)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Carum carvi</i> (Caraway)	<i>Alternaria</i> spp., <i>A. flavus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>A. terreus</i> , <i>Fusarium</i> spp., <i>Penicillium</i> spp., <i>Rhizoctonia</i> spp.	Abou-Arab et al., 1999
<i>Cardiospermum halicacabum</i> (Heart Seed)	<i>A. flavus</i> , <i>A. niger</i> , <i>R. stolonifer</i> , <i>Trichoderma</i> spp., other moulds	Abeywickrama and Bean, 1991
<i>Carum ajmoda</i> (Cellary)	<i>Aspergillus</i> spp., <i>Fusarium</i> spp., <i>R. stolonifer</i>	Chourasia, 1995
<i>Cassia</i> spp. (Senna)	<i>A. flavus</i> , <i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998; Rizzo et al., 2004
<i>Cassia fistula</i> (Golden Shower Tree)	<i>A. flavus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>F. moniliforme</i> , <i>P. citrinum</i> , <i>R. stolonifer</i>	Roy and Kumari, 1991
<i>Cecropia adenopus</i> (Ambay)	<i>A. flavus</i> , <i>A. ochraceus</i> , <i>F. oxysporum</i>	Rizzo et al., 2004
<i>Centella asiatica</i> (Gotu kola)	<i>A. flavus</i> , <i>P. janthinellum</i> , <i>R. stolonifer</i> , other moulds	Abeywickrama and Bean, 1991
<i>Chenopodium</i> sp. (Paico)	<i>A. ochraceus</i> , <i>F. compactum</i>	Rizzo et al., 2004
<i>Cinnamomum zeylanicum</i> (Cinnamon)	<i>Aspergillus</i> spp., <i>Chaetomium</i> spp., <i>Mucor</i> spp., <i>Syncephalastrum racemosum</i> , other moulds	Hitokoto et al., 1978; Chourasia, 1995; Guglielminetti et al., 1996
<i>Citrus aurantium</i> (Bitter Orange)	<i>A. flavus</i>	Rizzo et al., 2004
<i>Citrus sinensis</i> (Orange tree leaves)	<i>A. candidus</i> , <i>A. flavipes</i> , <i>A. flavus</i> , <i>A. fumigatus</i> , <i>A. glaucus</i> , <i>A. niger</i> , <i>A. terreus</i> , <i>Cladosporium</i> spp., <i>Fusarium</i> spp., <i>Mucor</i> spp., <i>Paecilomyces</i> spp., <i>Penicillium</i> spp., other moulds	Martins et al., 2001a
<i>Clerodendrum serratum</i>	<i>A. flavus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>Fusarium</i> spp., <i>F. moniliforme</i> , <i>Penicillium</i> spp., <i>P. citrinum</i>	Roy and Chourasia, 1990a
<i>Cnicus benedictus</i> (Blessed Thistle)	<i>A. flavus</i>	Rizzo et al., 2004
<i>Coriandrum sativum</i> (Coriander)	<i>A. flavus</i> , <i>A. glaucus</i> , <i>A. niger</i> , <i>Cylindrocarpon lichenicola</i> , <i>Syncephalastrum racemosum</i>	Guglielminetti et al., 1996; Rizzo et al., 2004

(Coptis)	<i>Aspergillus</i> spp., <i>A. flavus</i> , <i>A. niger</i> , <i>Mucor</i> spp., <i>Penicillium</i> spp.	Hitokoto et al., 1978
<i>Crataegus oxyacantha</i> (Hawthorn)	<i>A. flavus</i>	Rizzo et al., 2004
<i>Cuminum cyminum</i> (Cumin)	<i>Absidia</i> spp., <i>Aspergillus</i> spp., <i>A. aureolus</i> , <i>A. fumigatus</i> , <i>A. niger</i> , <i>Circinella</i> spp., <i>Cunninghamella</i> spp., <i>Fusarium</i> spp., <i>Mucor</i> spp., <i>Penicillium</i> spp., <i>P. janthinellum</i> , <i>Rhizopus</i> spp., <i>R. stolonifer</i> , <i>Scopulariopsis</i> spp., <i>Trichoderma</i> spp., other moulds	Chourasia, 1995; Guglielminetti et al., 1996; García et al., 2001
(Curcuma)	<i>A. glaucus</i> , <i>A. ochraceus</i>	Guglielminetti et al., 1996
<i>Cymbopogon nardus</i> (Citronella)	<i>A. glaucus</i> , <i>P. brevi-compactum</i>	Guglielminetti et al., 1996
<i>Cynara scolymus</i> (Artichoke)	<i>A. ochraceus</i> , <i>F. oxysporum</i>	Rizzo et al., 2004
<i>Cynodon dactylon</i> (Bermuda Grass)	<i>A. flavus</i> , <i>A. ochraceus</i> , <i>F. equiseti</i>	Rizzo et al., 2004
<i>Cyperus rotundus</i> (Nut Grass)	<i>Alt. alternata</i> , <i>Aspergillus</i> spp., <i>Chaetomium</i> spp., <i>Curvularia</i> spp., <i>Fusarium</i> spp., <i>Penicillium</i> spp., <i>R. stolonifer</i> , <i>T. viride</i> , other moulds	Roy and Chourasia, 1989
<i>Echium plantagineum</i> (Purple Viper's Bugloss)	<i>A. flavus</i> , <i>A. ochraceus</i>	Rizzo et al., 2004
<i>Elettaria cardamomum</i> (Cardamom)	<i>Alt. alternata</i> , <i>Aspergillus</i> spp., <i>Curvularia</i> spp., <i>Em. nidulans</i> , <i>Fusarium</i> spp., <i>Mucor</i> spp., <i>Penicillium</i> spp., <i>R. stolonifer</i> , <i>T. viride</i> , other moulds	Chourasia, 1995
<i>Eleutherococcus senticosus</i> (Siberian Ginseng root)	<i>A. versicolor</i> , <i>E. chevalieri</i> , <i>E. rubrum</i> , <i>Penicillium</i> spp., <i>Rhizopus</i> spp.	Tournas et al., 2006
Elder flower	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Emblica officinalis</i> (Indian gooseberry)	<i>Aspergillus</i> spp., <i>Chaetomium</i> spp., <i>Curvularia</i> spp., <i>Em. nidulans</i> , <i>Fusarium</i> spp., <i>R. stolonifer</i> , <i>T. viride</i> , other moulds	Chourasia, 1995
<i>Equisetum arvense</i> (Horsetail)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Equisetum giganteum</i> (Giant horsetail)	<i>A. flavus</i> , <i>A. ochraceus</i> , <i>F. equiseti</i> , <i>F. verticillioides</i>	Rizzo et al., 2004
<i>Erythraea chilensis</i>	<i>F. verticillioides</i>	Rizzo et al., 2004
<i>Evolvulus alsinoides</i> (Dwarf Morning-glory)	<i>Abs. corymbifera</i> , <i>Alt. alternata</i> , <i>A. flavus</i> , <i>A. niger</i> , <i>C. herbarum</i> , <i>Curvularia</i> sp., <i>Fusarium</i> sp., <i>P. italicum</i> , <i>T. viride</i> , <i>Umbelopsis</i> sp.	Singh et al., 2008
<i>Fagonia cretica</i> (Cretan prickly clover)	<i>Alt. alternata</i> , <i>Alt. phragmospora</i> , <i>Alt. tenuissima</i> , <i>A. flavus</i> , <i>A. niger</i> , <i>A. sydowii</i> , <i>A. tamarii</i> , <i>Chaetomium globosum</i> , <i>C. herbarum</i> , <i>C. sphaerospermum</i> , <i>Cochliobolus lunatus</i> , <i>F. moniliforme</i> , <i>F. oxysporum</i> , <i>Gliocladium catenulatum</i> , <i>P. chrysogenum</i> , <i>Phoma herbarum</i> , <i>Stachybotrys chartarum</i> , <i>U. atrum</i> , <i>U. Botrytis</i>	Abdel-Hafez and Naggar, 2006
<i>Foeniculum vulgare</i> (Fennel)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998

<i>Gardenia jasminoidis</i> (Gardenia fruits)	<i>A. flavus</i> , <i>A. glaucus</i> , <i>A. niger</i> , <i>A. terreus</i> , <i>A. ustus</i> , <i>Mucor</i> spp., <i>Penicillium</i> spp., <i>Rhizopus</i> spp., other moulds	Hitokoto <i>et al.</i> , 1978
<i>Gentiana gilliesii</i>	<i>A. ochraceus</i>	Rizzo <i>et al.</i> , 2004
<i>Gentiana lutea</i> (Yellow Gentian)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Glycyrrhiza glabra</i> (Liquorice)	<i>Abs. corymbifera</i> , <i>Aspergillus</i> spp., <i>A. flavus</i> , <i>A.</i> <i>glaucus</i> , <i>A. ochraceus</i> , <i>A. niger</i> , <i>A. terreus</i> , <i>Cladosporium</i> spp., <i>C. herbarum</i> , <i>Fusarium</i> spp., <i>Penicillium</i> spp., <i>P. italicum</i> , <i>T. viride</i> , <i>Rhizopus</i> spp., other moulds	Hitokoto <i>et al.</i> , 1978; Roy and Chourasia, 1990b; Singh <i>et al.</i> , 2008
<i>Gmelina arborea</i> (Gmelina)	<i>Aspergillus</i> spp., <i>Botrytis cinerea</i> , <i>Curvularia</i> spp., <i>Drechslera</i> spp., <i>Fusarium</i> spp., <i>Mucor</i> spp., <i>Penicillium</i> spp., other moulds	Roy and Chourasia, 1989
<i>Graminis rhizoma</i> (Couch Grass)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Hamamelis virginiana</i> (Witch Hazel)	<i>A. flavus</i>	Rizzo <i>et al.</i> , 2004
<i>Holarrhena antidysenterica</i> (Tellicherry bark )	<i>Aspergillus</i> spp., <i>Chaetomium globosum</i> , <i>Curvularia</i> spp., <i>Mucor</i> spp., <i>Penicillium</i> spp., <i>Pestalotiopsis</i> spp., <i>R. stolonifer</i> , other moulds	Roy and Chourasia, 1990b
<i>Hydnocarpus laurifolia</i>	<i>Alt. alternata</i> , <i>A. flavus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>Chaetomium</i> spp., <i>Curvularia</i> spp., <i>F. moniliforme</i> , <i>M.</i> <i>mucedo</i> , <i>P. citrinum</i> , <i>R. stolonifer</i>	Roy and Kumari, 1991
<i>Hygrophila spinosa</i> (Hydrophilia)	<i>Alt. alternata</i> , <i>Aspergillus</i> spp., <i>Chaetomium</i> spp., <i>Fusarium</i> spp., <i>Memnoniella echinata</i> , <i>Pestalotiopsis</i> spp., Other moulds	Roy and Chourasia, 1989
<i>Ichnocarpus frutescens</i> (Ichnocarpus)	<i>Aspergillus</i> spp., <i>Botrytis cinerea</i> , <i>Curvularia</i> spp., <i>Fusarium</i> spp., <i>Memnoniella echinata</i> , <i>Penicillium</i> spp., <i>R. stolonifer</i> , <i>T. viride</i> , other moulds	Roy and Chourasia, 1990b
<i>Jatropha curcas</i> (Physic nut )	<i>Aspergillus</i> spp., <i>Penicillium</i> spp., <i>T. viride</i>	Efuntoye, 1996
<i>Juniperus communis</i> (Juniper)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Laurus nobilis</i> (Bay leaves/ Laurel)	<i>Alternaria</i> spp., <i>A. fumigatus</i> , <i>A. niger</i> , <i>Aspergillus</i> spp., <i>Cladosporium</i> spp., <i>Cunninghamella</i> spp., <i>Monilia</i> spp., <i>Paecilomyces</i> spp., <i>Penicillium</i> spp., <i>Trichoderma</i> spp.	García <i>et al.</i> , 2001
<i>Lepidium sativum</i> (Garden cress )	<i>F. solani</i>	Rizzo <i>et al.</i> , 2004
<i>Mangifera indica</i> (Mango)	<i>Alt. humicola</i> , <i>Aspergillus</i> spp., <i>Fusarium</i> spp., <i>M.</i> <i>fragilis</i> , <i>Penicillium</i> spp., <i>Rhizopus</i> spp.	Efuntoye, 1996
<i>Marrubium vulgare</i> (White Horehound)	<i>A. flavus</i> , <i>A. ochraceus</i> , <i>F. equiseti</i>	Rizzo <i>et al.</i> , 2004
<i>Matricaria chamomilla</i> , <i>Chamomilla recutita</i> (Chamomile)	<i>Absidia</i> spp., <i>A. candidus</i> , <i>A. flavipes</i> , <i>A. flavus</i> , <i>A.</i> <i>fumigatus</i> , <i>A. glaucus</i> , <i>A. niger</i> , <i>A. terreus</i> , <i>Cladosporium</i> spp., <i>Fusarium</i> spp., <i>F. compactum</i> , <i>Mucor</i> spp., <i>Paecilomyces</i> spp., <i>Penicillium</i> spp., <i>R.</i> <i>nigricans</i> , other moulds	Pepeljnjak and Cvetnić, 1998 ; Martins <i>et al.</i> , 2001, Rizzo <i>et al.</i> , 2004



<i>Melissa officinalis</i> (Lemon Balm)	<i>A. flavus</i> , <i>F. equiseti</i> , <i>F. verticillioides</i>	Rizzo et al., 2004
<i>Mentha piperita</i> (Peppermint)	<i>Alternaria</i> spp., <i>A. flavus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>A. terreus</i> , <i>Fusarium</i> spp., <i>F. equiseti</i> , <i>Penicillium</i> spp., <i>R. nigricans</i> , <i>Trichoderma</i> spp.	Pepeljnjak and Cvetnić, 1998; Abou-Arab et al., 1999; Rizzo et al., 2004
<i>Mentha pulegium</i> <i>Lippia turbinata</i> (Pennyroyal)	<i>A. candidus</i> , <i>A. flavus</i> , <i>A. glaucus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>Cladosporium</i> spp., <i>Fusarium</i> spp., <i>Penicillium</i> spp., other moulds	Martins et al., 2001; Rizzo et al., 2004
<i>Mesua ferrea</i> (Ironwood)	<i>Aspergillus</i> spp., <i>Chaetomium</i> spp., <i>Drechslera</i> spp., <i>Fusarium</i> spp., <i>Penicillium</i> spp., <i>R. stolonifer</i> , <i>T. viride</i> , other moulds	Roy and Chourasia, 1989; Chourasia, 1995
<i>Minthostachys mollis</i> (Ecuadorian Mint)	<i>A. flavus</i> , <i>A. ochraceus</i> , <i>F. compactum</i> , <i>F. semitectum</i> , <i>F. verticillioides</i>	Rizzo et al., 2004
<i>Morinda lucida</i>	<i>Aspergillus</i> spp., <i>Fusarium</i> spp., <i>Penicillium</i> spp., <i>Rhizopus</i> spp.	Efuntoye, 1996
<i>Brassica campestris</i> (Mustard)	<i>Alt. alternata</i> , <i>A. candidus</i> , <i>A. flavus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>Cladosporium</i> spp., <i>Colletotrichum acutatum</i> , <i>Curvularia lunata</i> , <i>Curvularia pallescens</i> , <i>Fusarium</i> spp., <i>F. moniliforme</i> , <i>F. semitectum</i> , <i>Helminthosporium</i> spp., <i>Memnoniella echinata</i> , <i>Monilia sitophila</i> , <i>P. citrinum</i> , <i>R. stolonifer</i>	Sahay and Prasad, 1990
<i>Origanum vulgare</i> (Oregano)	<i>Alt. alternata</i> , <i>Aspergillus</i> spp., <i>A. niger</i> , <i>A. versicolor</i> , <i>Chaetomium</i> spp., <i>Cunninghamella</i> spp., <i>Mucor</i> spp., <i>Nigrospora</i> spp., <i>Penicillium</i> spp., <i>Phoma</i> spp., <i>Rhizopus</i> spp., <i>Trichoderma</i> spp.	Guglielminetti et al., 1996; García et al., 2001
<i>Paeonia japonica</i> (Japanese peony roots)	<i>A. glaucus</i> , <i>A. nidulans</i> , <i>A. niger</i> , <i>A. versicolor</i> , <i>Mucor</i> spp., <i>Penicillium</i> spp., <i>Rhizopus</i> spp., other moulds	Hitokoto et al., 1978
<i>Panax ginseng</i> (Chinese Ginseng)	<i>Aspergillus</i> spp., <i>A. niger</i> , <i>Cladosporium</i> spp., <i>E. chevalieri</i> , <i>Penicillium</i> spp., <i>Rhizopus</i> spp.	Tournas et al., 2006
<i>Panax quinquefolius</i> (American Ginseng root)	<i>A. flavus</i> , <i>A. niger</i> , <i>Chaetomium</i> spp., <i>Fusarium</i> spp., <i>Penicillium</i> spp., <i>Rhizopus</i> spp.	Tournas et al., 2006
<i>Passiflora coerulea</i> (Passion Flower)	<i>A. flavus</i> , <i>A. ochraceus</i> , <i>F. semitectum</i> , <i>F. subglutinans</i> , <i>F. verticillioides</i>	Rizzo et al., 2004
<i>Peganum harmala</i> (Syrian Rue)	<i>Alt. alternata</i> , <i>Alt. tenuissima</i> , <i>A. flavus</i> , <i>A. fumigatus</i> , <i>A. niger</i> , <i>A. tamarii</i> , <i>C. herbarum</i> , <i>C. macrocarpum</i> , <i>C. sphaerospermum</i> , <i>Cochliobolus lunatus</i> , <i>Cochliobolus spicifer</i> , <i>Epicoccum purpurascens</i> , <i>F. moniliforme</i> , <i>F. oxysporum</i> , <i>Gliocladium catenulatum</i> , <i>P. chrysogenum</i> , <i>P. oxalicum</i> , <i>Phoma herbarum</i> , <i>Stachybotrys chartarum</i> , <i>Stemphylium botryosum</i> , <i>Trimmatostroma salicis</i> , <i>U. atrum</i> , <i>U. botrytis</i> , <i>U. chartarum</i>	Abdel-Hafez and Naggat, 2006
<i>Petroselinum sativum</i> (Parsley root)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Picrorhiza kurroa</i> (Kuru)	<i>A. flavus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>Fusarium</i> spp., <i>F. moniliforme</i> , <i>Penicillium</i> spp., <i>P. citrinum</i>	Roy and Chourasia, 1990a
<i>Pimpinella anisum</i> (Anise)	<i>Alternaria</i> spp., <i>A. flavus</i> , <i>A. niger</i> , <i>Fusarium</i> spp., <i>Penicillium</i> spp., <i>Trichoderma</i> spp.	Abou-Arab et al., 1999

<i>Piper betle</i> (Betel nut)	<i>Alt. alternata</i> , <i>A. flavus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>Chaetomium</i> spp., <i>Curvularia</i> spp., <i>F. moniliforme</i> , <i>M. mucedo</i> , <i>P. citrinum</i> , <i>R. stolonifer</i>	Roy and Kumari, 1991
<i>Piper longum</i> (Indian long pepper)	<i>Alt. alternata</i> , <i>Aspergillus</i> spp., <i>Chaetomium</i> spp., <i>Curvularia</i> spp., <i>Em. nidulans</i> , <i>Fusarium</i> spp., <i>Mucor</i> spp., <i>Penicillium</i> spp., <i>R. stolonifer</i> , <i>T. viride</i> , other moulds	Chourasia, 1995
<i>Piper nigrum</i> (Black pepper)	<i>Alt. alternata</i> , <i>Aspergillus</i> spp., <i>Chaetomium</i> spp., <i>Curvularia</i> spp., <i>Em. nidulans</i> , <i>Fusarium</i> spp., <i>Mucor</i> spp., <i>Penicillium</i> spp., <i>T. viride</i> , other moulds	Chourasia, 1995
(Plactycodon)	<i>A. flavus</i> , <i>A. glaucus</i> , <i>A. nidulans</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>Cladosporium</i> spp., <i>Penicillium</i> spp., <i>Rhizopus</i> spp., other moulds	Hitokoto et al., 1978
<i>Plumbago zeylanica</i> ( White Leadwort)	<i>Abs. corymbifera</i> , <i>Aspergillus</i> spp., <i>A. flavus</i> , <i>A. niger</i> , <i>Penicillium</i> spp., <i>P. italicum</i> , <i>Rhizopodopsis</i> sp., <i>Rhizopus</i> spp., <i>T. viride</i> , <i>Umbelopsis</i> sp., <i>Mucor</i> sp.	Efuntoye, 1996; Singh et al., 2008
<i>Potentilla erecta</i> (Tormentil root)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Rheum</i> sp. (Rhubarb)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Ruta graveolens</i> (Rue)	<i>A. flavus</i>	Rizzo et al., 2004
<i>Salvia officinalis</i> (Garden sage)	<i>A. candidus</i> , <i>A. flavipes</i> , <i>A. fumigatus</i> , <i>A. glaucus</i> , <i>Cladosporium</i> spp., <i>Fusarium</i> spp., <i>Penicillium</i> spp., <i>R. nigricans</i> , other moulds	Pepeljnjak and Cvetnić, 1998; Martins et al., 2001
<i>Saraca indica</i> (Ashoka)	<i>Aspergillus</i> spp., <i>Chaetomium</i> spp., <i>Penicillium</i> spp.	Chourasia, 1995
<i>Scorzonera undulata</i>	<i>Alt. alternata</i> , <i>Alt. tenuissima</i> , <i>A. flavus</i> group, <i>A. niger</i> , <i>A. sydowii</i> , <i>A. terreus</i> , <i>C. herbarum</i> , <i>C. macrocarpum</i> , <i>C. sphaerospermum</i> , <i>Cochliobolus lunatus</i> , <i>Cochliobolus spicifer</i> , <i>F. moniliforme</i> , <i>F. oxysporum</i> , <i>F. solani</i> , <i>P. chrysogenum</i> , <i>P. citrinum</i> , <i>P. funiculosum</i> , <i>Phoma herbarum</i> , <i>Stachybotrys chartarum</i> , <i>Stemphylium botryosum</i> , <i>U. atrum</i> , <i>U. botrytis</i>	Abdel-Hafez and Naggar, 2006
<i>Scutellaria baicalensis</i> (Skullcap roots)	<i>A. flavus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>A. terreus</i> , <i>Penicillium</i> spp.	Hitokoto et al., 1978
<i>Smilax campestris</i>	<i>A. ochraceus</i>	Rizzo et al., 2004
<i>Solanum nigrum</i> (Black Nightshade)	<i>Alt. alternata</i> , <i>Aspergillus</i> spp., <i>Botrytis cinerea</i> , <i>Memnoniella echinata</i> , <i>Mucor</i> spp., <i>Penicillium</i> spp., <i>Pestalotiopsis</i> spp., other moulds	Roy and Chourasia, 1989
<i>Strychnos nux-vomica</i> (Nux vomica)	<i>Alt. alternata</i> , <i>Aspergillus</i> spp., <i>A. candidus</i> , <i>A. clavatus</i> , <i>A. flavus</i> , <i>A. luchuensis</i> , <i>A. nidulans</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>A. sydowii</i> , <i>Chaetomium globosum</i> , <i>C. herborum</i> , <i>Curvularia</i> spp., <i>Fusarium</i> spp., <i>F. chlamydosporum</i> , <i>F. equiseti</i> , <i>Gliocladium penicilloides</i> , <i>Mucor</i> spp., <i>M. mucedo</i> , <i>Penicillium</i> spp., <i>P. citrinum</i> , <i>R. stolonifer</i> , <i>Stachybotrys</i> spp., <i>T. viride</i> , other moulds	Dutta and Roy, 1987; Roy and Chourasia, 1990b

<i>Strychnos potatorum</i> (Cleaning Nut Tree)	<i>Alt. alternata</i> , <i>A. candidus</i> , <i>A. clavatus</i> , <i>A. flavus</i> , <i>A. luchuensis</i> , <i>A. nidulans</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>A. sydowii</i> , <i>C. herborum</i> , <i>F. equiseti</i> , <i>F. moniliforme</i> , <i>F. semitectum</i> , <i>Hormodendrum pallidum</i> , <i>M. mucedo</i> , <i>M. pusillus</i> , <i>Paecilomyces</i> spp., <i>Penicillium</i> spp., <i>P. citrinum</i> , <i>R. stolonifer</i>	Dutta and Roy, 1987
<i>Symphytum officinale</i> (Comfrey root)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Taxus baccata</i> (Yew)	<i>Aspergillus</i> spp., <i>Curvularia</i> spp., <i>Fusarium</i> spp., <i>T. viride</i>	Chourasia, 1995
<i>Terminalia chebula</i> (Chebolic Myrobalan)	<i>Alt. alternata</i> , <i>A. flavus</i> , <i>A. niger</i> , <i>A. terreus</i> , <i>Curvularia</i> sp., <i>Fusarium</i> sp., <i>P. italicum</i> , <i>T. viride</i>	Singh et al., 2008
<i>Thymus vulgaris</i> (Thyme)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Tilia</i> spp. (Linden)	<i>Alternaria</i> spp., <i>A. candidus</i> , <i>A. flavus</i> , <i>A. fumigatus</i> , <i>A. glaucus</i> , <i>A. niger</i> , <i>A. ochraceus</i> , <i>A. terreus</i> , <i>Cladosporium</i> spp., <i>Fusarium</i> spp., <i>F. equiseti</i> , <i>F. verticillioides</i> , <i>Mucor</i> spp., <i>Penicillium</i> spp., <i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998; Abou-Arab et al., 1999; Martins et al., 2001; Rizzo et al., 2004,
<i>Tribulus terrestris</i> (Small Caltrops)	<i>Aspergillus</i> spp., <i>A. flavus</i> , <i>A. niger</i> , <i>A. wentii</i> , <i>Fusarium</i> spp., <i>Mucor</i> spp., <i>P. janthinellum</i> , <i>Stachybotrys</i> spp., <i>T. viride</i> , other moulds	Roy and Chourasia, 1990b; Abeywickrama and Bean, 1991
<i>Urtica dioica</i> , <i>Urtica urens</i> (Nettle leaves)	<i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998
<i>Valeriana officinalis</i> (Valerian)	<i>A. flavus</i> , <i>A. ochraceus</i> , <i>F. equiseti</i> , <i>F. proliferatum</i> , <i>F. semitectum</i> , <i>R. nigricans</i>	Pepeljnjak and Cvetnić, 1998; Rizzo et al., 2004
<i>Vernonia amygdalina</i> (Bitter Leaf)	<i>Aspergillus</i> spp., <i>Fusarium</i> spp., <i>G. albidum</i> , <i>M. fragilis</i> , <i>Penicillium</i> spp.	Efuntoye, 1996
<i>Viscum album</i> (Mistletoe)	<i>A. flavus</i>	Rizzo et al., 2004
<i>Xylopiya aethiopica</i> (Senegal Pepper)	<i>Aspergillus</i> spp., <i>C. bantianum</i> , <i>Fusarium</i> spp., <i>Rhizopus</i> spp.	Efuntoye, 1996
<i>Zea mays</i> (Corn silk)	<i>Absidia</i> spp., <i>A. candidus</i> , <i>A. flavus</i> , <i>A. fumigatus</i> , <i>A. glaucus</i> , <i>A. niger</i> , <i>A. terreus</i> , <i>Cladosporium</i> spp., <i>Fusarium</i> spp., <i>Mucor</i> spp., <i>Penicillium</i> spp.	Martins et al., 2001
<i>Zingiber officinale</i> (Ginger)	<i>Aspergillus</i> spp., <i>A. flavus</i> , <i>A. glaucus</i> , <i>A. nidulans</i> , <i>A. niger</i> , <i>A. terreus</i> , <i>A. versicolor</i> , <i>Chaetomium</i> spp., <i>Fusarium</i> spp., <i>Penicillium</i> spp., <i>Rhizopus</i> spp., <i>R. stolonifer</i> , <i>T. viride</i> , other moulds	Hitokoto et al., 1978; Chourasia, 1995

(1) **A.: Aspergillus**, **Abs.: Absidia**, **Alt.: Alternaria**, **B.: Botrytis**, **C.: Cladosporium**, **Cur.: Curvularia**, **E.: Eurotium**, **Em.: Emericella**, **F.: Fusarium**, **G.: Geothichum**, **M.: Mucor**, **P.: Penicillium**, **R.: Rhizopus**, **T.: Trichoderma** and **U.: Ulocladium**.

### Mycotoxins in Herbs

Nowadays, the increasing consumption of herbal products may lead to an increase in the intake of mycotoxins. Mycotoxin contamination in herbs has been described in several studies (Tables N° 3 and N°

4). Figure N° 1 shows the chemical structures of the main mycotoxins found in this kind of commodities.

The most studied mycotoxins in herbs have been AF and OTA, followed by fumonisins (FBs). Contamination levels for these mycotoxins ranged

from not detected up to 1,420 µg/kg for AF, 2525.8 µg/kg for OTA and 700 µg/kg for FB.

Hitokoto *et al.*, (1978) were the only ones which analysed the presence of sterigmatocystin in several herbal products (cinnamon, corktree bark, gardenia fruits, ginger, grey atractylopes, Japanese atractylodes, Japanese golden-thread, liquorice, Japanese peony, mountain tea, pickly ash fruit and white leadwort), although this toxin was not detected in any of the samples.

Although there is little information about interaction between mycotoxins, and combined toxicity evaluation is quite complicated, it is expected that mycotoxins with similar mode of action would have, at least, an additive effect (Speijers and Speijers, 2004). There are only a few studies of simultaneous occurrence of mycotoxins in herbs

(Hitokoto, 1978; Chourasia, 1995; Patel *et al.*, 1996; Halt, 1998; Santos *et al.*, 2009).

Although the European Union has established legal limits for AF, OTA, deoxynivalenol (DON), zearalenone (ZEA) and FBs in a wide variety of food related items, in the case of spices and herbs there is only official legislation for AF and OTA contamination in *Curcuma longa* (turmeric), *Mystica fragrans* (nutmeg) *Pipper* spp. (pepper) and *Zingiber officinale* (ginger), the limits being 10 and 30 µg/kg, respectively (EC, 2006a; EU, 2010a). The European legislation also set limits for OTA in *Glycyrriza* spp. (liquorice) and liquorice extracts, set at 20 and 80 µg/kg, respectively (EU, 2010a). On the other hand, the European Pharmacopeia establishes that AFB<sub>1</sub> should be tested in herbal products, but does not give any application limit (European Pharmacopeia, 2006).

**Table N° 3**  
**Incidence of *Aspergillus* and *Penicillium* mycotoxins in herbal products<sup>(1)</sup>.**

Specie name (Common name)	AFB <sub>1</sub> (µg/kg)	AFB <sub>2</sub> (µg/kg)	AFG <sub>1</sub> (µg/kg)	AFG <sub>2</sub> (µg/kg)	AFt (µg/kg)	OTA (µg/kg)	Citrinin (µg/kg)	Reference
<i>Acacia catechu</i> (Cutch Tree bark)	90	-	-	-	-	-	-	Roy <i>et al.</i> , 1988
<i>Acacia concinna</i> (Shikakai)	80-1,130	-	-	-	-	-	10-760	Roy and Kumari, 1991
<i>Achillea millefolium</i> (Yarrow)	ND	-	-	-	-	ND	-	Halt, 1998
<i>Achyranthes aspera</i> (Prickly-Chaff)	750	-	-	-	-	-	Detected	Roy and Chourasia, 1990a
<i>Aconitum ferox</i> (Indian Aconite roots)	ND	-	-	-	-	-	-	Roy <i>et al.</i> , 1988
<i>Acorus calamus</i> (Sweet Flag)	1,100	-	-	-	-	-	Detected	Roy and Chourasia, 1990a
<i>Adhatoda vasica</i> (Malabar Nut)	670	-	-	-	-	-	-	Roy and Chourasia, 1990a
<i>Aerva lanata</i> (Boor)	500	-	-	-	-	-	-	Abeywickrama and Bean, 1991
<i>Allium sativum</i> (Garlic)	- ND	- ND	- ND	- ND	ND ND	ND -	- -	Patel <i>et al.</i> , 1996; Romagnoli <i>et al.</i> , 2007
<i>Althaea officinalis</i> (Marshmallow)	ND	-	-	-	-	ND	-	Halt, 1998
<i>Andrographis paniculata</i> (King of bitters)	-	-	-	-	-	740- 1,390	-	Roy and Kumar, 1993
<i>Argyreia speciosa</i> (Elephant creeper)	90-2,810	50-300	-	-	-	-	-	Kumari <i>et al.</i> , 1989

<i>Asparagus racemosus</i> (Asparagus)	1,570-2,330	220-1,040	-	-	-	-	-	Kumar and Roy, 1993
<i>Atractylodes japonica</i> (Japanese Atractylodes)	ND	-	-	-	-	ND	-	Hitokoto <i>et al.</i> , 1978
<i>Atractylodes lancea</i> (Grey Atractylodes Tuber )	ND	-	-	-	-	ND	-	Hitokoto <i>et al.</i> , 1978
<i>Arctium</i> sp. (Burdock root)	-	-	-	-	2.6- 10.3	<LD	<LD-25.8	Santos <i>et al.</i> , 2009
<i>Betula alba</i> (Birch)	ND	-	-	-	-	ND	-	Halt, 1998
<i>Blepharis edulis</i>	10-1,040	-	-	-	-	-	ND	Roy and Kumari, 1991
<i>Brassica campestris</i> (Mustard)	-	-	-	-	trace- 1,420	-	-	Sahay and Prasad, 1990
<i>Caesalpinea digyna</i> (Teri Pods)	80-1,180	-	-	-	-	-	ND	Roy and Kumari, 1991
<i>Camellia sinensis</i> (Green tea)	ND	ND	ND	ND	ND	-	-	Romagnoli <i>et al.</i> , 2007
<i>Camellia sinensis</i> (Red tea)	-	-	-	-	801.1- 853.4	3.7-4.0	18.0-22.3	Santos <i>et al.</i> , 2009
<i>Camellia sinensis</i> (White tea)	-	-	-	-	94.2- 254.0	<LD-1.1	<LD-19.7	Santos <i>et al.</i> , 2009
<i>Carum cravi</i> (Caraway)	-	-	-	-	ND	-	-	Abou-Arab <i>et al.</i> , 1999
<i>Cassia fistula</i> (Golden Shower Tree)	80-1,110	-	-	-	-	-	10-690	Roy and Kumari, 1991
	1.5-18.6	-	-	-	-	-	-	Arranz <i>et al.</i> , 2006
	ND - 255	-	-	-	-	-	-	Müller and Basedow, 2007
<i>Cassia</i> spp. (Senna)	-	-	-	-	15.8- 434.3	0.8-3.1	<LD-68.6	Santos <i>et al.</i> , 2009
<i>Cinnamomum</i> <i>zeylanicum</i> (Cinnamon)	ND	-	-	-	-	ND	-	Hitokoto <i>et al.</i> , 1978
	0.98	ND	ND	ND	0.98	-	-	Romagnoli <i>et al.</i> , 2007
<i>Clerodendrum</i> <i>serratum</i>	510	-	-	-	-	-	-	Roy and Chourasia, 1990a
<i>Coptis japonica</i> (Japanese Gold- Thread)	ND	-	-	-	-	ND	-	Hitokoto <i>et al.</i> , 1978
	790	-	-	-	-	-	-	Roy <i>et al.</i> , 1988
<i>Coriandrum sativum</i> (Coriander)	-	-	-	-	0.7	4.0	-	Patel <i>et al.</i> , 1996
	-	-	-	-	-	ND	-	Lino <i>et al.</i> , 2006
	ND	ND	ND	ND	ND	-	-	Romagnoli <i>et al.</i> , 2007
<i>Crataegus</i> <i>oxyacantha</i> (Hawthorn)	ND	ND	ND	ND	ND	-	-	Romagnoli <i>et al.</i> , 2007

<i>Cuminum cyminum</i> (Cumin)	ND	ND	ND	ND	ND	-	-	Romagnoli et al., 2007
<i>Curcuma</i> sp. (Turmeric)	ND	ND	ND	ND	ND	-	-	Romagnoli et al., 2007
<i>Cynara scolymus</i> (Artichoke immature florets)	-	-	-	-	10.7- 12.1	<LD-5.0	<LD-29.8	Santos et al., 2009
(Devil's Claw)	ND-0.2	-	-	-	-	-	-	Arranz et al., 2006
<i>Diospyros</i> <i>embryopteris</i> (Evergreen tree)	250	-	-	-	-	-	-	Roy et al., 1988
	-	-	-	-	-	90-890	-	Roy and Kumar, 1993
<i>Embllica officinalis</i> (Indian gooseberry)	280-1,070	130-670	-	-	-	-	-	Kumar and Roy, 1993
	-	-	-	-	-	930- 1,740	-	Roy and Kumar, 1993
<i>Embllica ribes</i> (False Pepper)	360	-	-	-	-	-	-	Roy et al., 1988
	80-2,660	50-550	-	-	-	-	-	Kumari et al., 1989
<i>Foeniculum vulgare</i> (Fennel)	-	-	-	-	1.2	ND	-	Patel et al., 1996
	ND	ND	ND	ND	ND	-	-	Romagnoli et al., 2007
<i>Gardenia jasminoidis</i> (Gardenia fruits)	ND	-	-	-	-	ND	-	Hitokoto et al., 1978
<i>Ginkgo biloba</i> (Ginkgo leaves)	-	-	-	-	23.0- 23.3	0.8-1.1	298.7-354.8	Santos et al., 2009
	ND	-	-	-	-	ND	-	Hitokoto et al., 1978
	590	-	-	-	-	-	-	Roy et al., 1988
<i>Glycyrrhiza glabra</i> (Liquorice)	170	-	-	-	-	50	-	Roy and Chourasia, 1990b
	-	-	-	-	-	ND - 216.5	-	Bresch et al., 2000
	-	-	-	-	-	1.4- 252.8	-	Ariño et al., 2007
<i>Hibiscus</i> <i>abelmoschus</i> (Muskseed)	850	-	-	-	-	-	-	Roy et al., 1988
<i>Holarrhena</i> <i>antidysenterica</i> (Tellicherry bark )	290	-	-	-	-	-	80	Roy and Chourasia, 1990b
	-	-	-	-	-	1,140- 2,340	-	Roy and Kumar, 1993
<i>Hydnocarpus</i> <i>laurifolia</i>	20-650	-	-	-	-	-	10-490	Roy and Kumari, 1991
<i>Ichnocarpus</i> <i>frutescens</i> (Ichnocarpus)	510	-	-	-	-	-	-	Roy and Chourasia, 1990b
<i>Illicium verum</i> (Star anise)	-	-	-	-	94.8- 104.2	<LD	<LD	Santos et al., 2009
<i>Laurus nobilis</i> (Laurel)	ND	ND	ND	ND	ND	-	-	Romagnoli et al., 2007
<i>Lippia citriodora</i> (Lemon verbena)	-	-	-	-	31.1- 37.7	<LD-1.5	29.6-79.1	Santos et al., 2009

<i>Matricaria chamomilla</i> <i>Anthemis</i> sp. (Chamomile)	ND - -	- - -	- - -	- - -	- ND 35.8-161.0	ND - 0.8-1.0	- - 31.7-49.3	Halt, 1998 Abou-Arab et al., 1999 Santos et al., 2009
<i>Maytenus ilicifolia</i> (Espineira Santa)	ND	ND	ND	ND	ND	-	-	Braga et al., 2005
<i>Melissa officinalis</i> (Lemon Balm)	ND ND	- ND	- ND	- ND	- ND	ND -	- -	Halt, 1998 Romagnoli et al., 2007
<i>Mentha</i> sp. (Spearmint)	-	-	-	-	16.6-29.7	1.1-1.4	41.0-43.3	Santos et al., 2009
<i>Mentha piperita</i> (Peppermint)	-	-	-	-	ND	-	-	Abou-Arab et al., 1999
<i>Morus alba</i> (Weeping Mulberry)	ND	-	-	-	-	ND	-	Halt, 1998
<i>Mucuna pruriens</i> (Velvetbean)	1,160	-	-	-	-	-	-	Roy et al., 1988
<i>Ocimum basilicum</i> (Basil)	ND	ND	ND	ND	ND	-	-	Romagnoli et al., 2007
<i>Origanum vulgare</i> (Marjoram)	ND	ND	ND	ND	ND	-	-	Romagnoli et al., 2007
<i>Olea europaea</i> (Olive leaves)	-	-	-	-	58.0-77.6	<LD-1.3	<LD-14.9	Santos et al., 2009
<i>Paeonia japonica</i> (Japanese peony roots)	ND	-	-	-	-	ND	-	Hitokoto et al., 1978
<i>Panax quinquefolium</i> (American ginseng)	-	-	-	-	ND-16	-	-	D' Ovidio et al., 2006
<i>Papaver somniferum</i> (Poppy seeds)	ND	ND	ND	ND	ND	-	-	Romagnoli et al., 2007
<i>Pavonia odorata</i> (Fragrant silky mallow)	870	-	-	-	-	-	-	Roy et al., 1988
<i>Petroselinum sativum</i> (Parsley)	ND	ND	ND	ND	ND	-	-	Romagnoli et al., 2007
<i>Peumus boldus</i> (Boldus)	-	-	-	-	32.2-86.6	1.2-1.6	15.7-62.7	Santos et al., 2009
<i>Phellodendron chinense</i> (Corktree bark)	ND	-	-	-	-	ND	-	Hitokoto et al. 1978
<i>Picrorhiza kurroa</i> (Kuru)	110	-	-	-	-	Detected	-	Roy and Chourasia, 1990a
<i>Pimpinella anisum</i> (Anise)	-	-	-	-	ND	-	-	Abou-Arab et al., 1999
<i>Piper betle</i> (Betel nut)	20-1,000	-	-	-	-	-	10-720	Roy and Kumari, 1991
<i>Piper longum</i> (Indian long pepper)	220	-	-	-	-	-	-	Roy et al., 1988

<i>Piper nigrum</i> (Black pepper)	1,200	-	-	-	-	-	-	Roy et al., 1988
	ND	ND	ND	ND	ND	-	-	Romagnoli et al., 2007
(Plactycodon)	ND	-	-	-	-	ND	-	Hitokoto et al., 1978
<i>Plantago lanceolata</i> (Ribgrass leaves)	-	-	-	-	12.6-16.1	0.9-1.1	<LD	Santos et al., 2009
<i>Plumbago zeylanica</i> (White Leadwort)	1,130	-	-	-	-	-	-	Roy et al., 1988
(Prickly Ash Fruit)	ND	-	-	-	-	ND	-	Hitokoto et al., 1978
<i>Psoralea corylifolia</i>	-	-	-	-	-	70-1,100	-	Roy and Kumar, 1993
<i>Rhamnus frangula</i> (Frangula bark)	-	-	-	-	32.1-64.7	1.5-4.2	26.7-38.4	Santos et al., 2009
<i>Rhamnus purshiana</i> (Cascara Sagrada)	ND	ND	ND	ND	ND	-	-	Ventura et al., 2004
<i>Rhamnus wighatii</i>	1830	-	-	-	-	-	-	Kumar and Roy, 1993
<i>Rheum officinalis</i> (Rhubarb stem)					35.7-71.2	2.1-13.9	42.2-42.9	Santos et al., 2009
<i>Rosa canina</i> (Rose hip)	ND	ND	ND	ND	ND	-	-	Romagnoli et al., 2007
<i>Rosmarinus officinalis</i> (Rosemary)	ND	ND	ND	ND	ND	-	-	Romagnoli et al., 2007
<i>Salvia fruticosa</i> , <i>Salvia officinalis</i> (Sage)	-	-	-	-	23.8-25.2	1.1-17.3	51.6-273.2	Santos et al., 2009
	ND	ND	ND	ND	ND	-	-	Romagnoli et al., 2007
<i>Sambucus nigra</i> (Elder)	ND	-	-	-	-	ND	-	Halt, 1998
<i>Scutellaria baicalensis</i> (Skullcap root)	ND	-	-	-	-	ND	-	Hitokoto et al., 1978
<i>Silybum marianum</i> (St Mary's thistle seeds)	-	-	-	-	10.9-11.5	<LD	<LD	Santos et al., 2009
<i>Solanum xanthocarpum</i> (Indian Nightshade)	140	-	-	-	-	-	-	Roy et al., 1988
<i>Strychnos nux-vomica</i> (Nux vomica)	670	-	-	-	-	100	-	Roy and Chourasia, 1990b
<i>Tacca aspera</i>	-	-	-	-	-	300-740	-	Roy and Kumar, 1993
<i>Taraxacum officinale</i> (Dandelion)	-	-	-	-	11.8-21.7	<LD-10.6	21.6-96.0	Santos et al., 2009
<i>Tephrosia purpurea</i> (Purple tephrosia)	420	-	-	-	-	-	-	Kumar and Roy, 1993
	-	-	-	-	-	940-1,580	-	Roy and Kumar, 1993



<i>Terminalia bellerica</i> (Belliric Myrobalan)	620	-	-	-	-	-	-	Roy et al., 1988
	180	-	-	-	-	-	-	Roy et al., 1988
<i>Terminalia chebula</i> (Chebulic Myrobalan)	1,430-2,190	570-1,340	230-670	-	-	-	-	Kumar and Roy, 1993
	-	-	-	-	-	90-1,230	-	Roy and Kumar, 1993
(Thyme)	ND	ND	ND	ND	ND	-	-	Romagnoli et al., 2007
<i>Tilia grandifolia</i> , <i>Tilia</i> sp. (Linden)	ND	-	-	-	-	traces	-	Halt, 1998
<i>Tinospora cordifolia</i>	420-860	-	-	-	-	-	-	Kumar and Roy, 1993
<i>Tribulus terrestris</i> (Small Caltrops)	420	-	-	-	-	-	-	Roy and Chourasia, 1990b
	-	-	-	-	-	140-1,300	-	Roy and Kumar, 1993
<i>Valeriana officinalis</i> (Valerian root)	-	-	-	-	6.2-15.8	0.8-1.8	<LD-20.5	Santos et al., 2009
<i>Verbena officinalis</i> (Vervain)	-	-	-	-	48.9-104.5	<LD-1.1	<LD-31.2	Santos et al., 2009
	ND	-	-	-	-	ND	-	Hitokoto et al., 1978
<i>Zingiber officinale</i> (Ginger)	<0.4-3.6	-	-	-	-	-	-	Arranz et al., 2006
	-	-	-	-	4.2-13.5	2.1-7.5	-	Patel et al., 1996

(1) ND: not detected, <LD: lower than limit of detection, AF: aflatoxin, AFt: total aflatoxins, OTA: ochratoxin A

Table N° 4  
Incidence of *Fusarium* mycotoxins in herbal products<sup>(1)</sup>

Specie name (Common name)	Fumonisin (µg/kg)	ZEA (µg/kg)	Trichothecenes (µg/kg)	Reference
<i>Achillea millefolium</i> (Yarrow)	-	ND	-	Halt, 1998
<i>Achyranthes aspera</i> (Prickly-Chaff)	-	Detected	-	Roy and Chourasia, 1990a
<i>Adhatoda vasica</i> (Malabar Nut)	-	Detected	-	Roy and Chourasia, 1990a
<i>Allium sativum</i> (Garlic)	ND	ND	DON: 14, FUS X: 5, NIV: 21	Patel et al., 1996
<i>Althaea officinalis</i> (Marshmallow)	-	ND	-	Halt, 1998
<i>Arctium</i> sp. (Burdock root)	<LD	<LD-10.9	DON: <LD, T2: 0.6-1.2	Santos et al., 2009
<i>Arctostaphylos uva-ursi</i> (Bearberry leaves)			DON: 5.2	Santos et al., 2009
<i>Betula alba</i> (Birch)	-	ND	-	Halt, 1998

<i>Camelia sinensis</i> (Black tea)	FB <sub>1</sub> : 80-280, FB <sub>2</sub> : ND	-	-	Martins <i>et al.</i> , 2001b
	FB <sub>1</sub> : ND-traces, FB <sub>2</sub> : ND	-	-	Omurtag and Yazicioğlu, 2004
<i>Camelia sinensis</i> (Green tea)	ND	-	-	Omurtag and Yazicioğlu, 2004
<i>Camelia sinensis</i> (Red tea)	<LD	4.5-11.2	DON: 149.1-179.9, T2: 40.6-42.8	Santos <i>et al.</i> , 2009
<i>Camelia sinensis</i> (White tea)	<LD	8.3-11.2	DON: <LD-60.0, T2: 34.5-42.8	Santos <i>et al.</i> , 2009
<i>Cassia</i> spp. (Senna)	86.7-96.7	7.1-8.4	DON: 20.5-35.2, T2: 2.4-3.0	Santos <i>et al.</i> , 2009
	FB <sub>1</sub> : ND-<LD, FB <sub>2</sub> : ND			Omurtag and Yazicioğlu, 2004
<i>Citrus sinensis</i> (Orange tree leaves)	FB <sub>1</sub> : 350-700, FB <sub>2</sub> : ND	-	-	Martins <i>et al.</i> , 2001b
<i>Clerodendrum serratum</i>	-	Detected	-	Roy and Chourasia, 1990a
<i>Coriandrum sativum</i> (Coriander)	ND	3.6-6.7	DON: 21	Patel <i>et al.</i> , 1996
<i>Cynara scolymus</i> (Artichoke immature florets)	<LD	7.2-7.8	DON: 165.0-200.2, T2: 17.8-29.8	Santos <i>et al.</i> , 2009
<i>Foeniculum vulgare</i> (Fennel)	ND	7.0	ND	Patel <i>et al.</i> , 1996
	ND	-	-	Omurtag and Yazicioğlu, 2004
<i>Ginkgo biloba</i> (Ginkgo leaves)	<LD	9.1-9.4	DON: 63.4-134.1, T2: 19.1-29.4	Santos <i>et al.</i> , 2009
<i>Glycyrrhiza glabra</i> (Liquorice)	ND	-	-	Omurtag and Yazicioğlu, 2004
	647	-	-	Santos <i>et al.</i> , 2009
<i>Illicium verum</i> (Star anise)	140.0-146.7	2.2-10.1	DON: 275.2-321.2, T2: 40.6-60.5	Santos <i>et al.</i> , 2009
<i>Laurus nobilis</i> (Laurel)	ND	-	-	Omurtag and Yazicioğlu, 2004
<i>Lippia citriodora</i> (Lemon verbena)	<LD	6.4-14.0	DON: 119.4-143.7, T2: 18.9-28.6	Santos <i>et al.</i> , 2009
<i>Matricaria chamomilla</i> <i>Anthemis</i> sp. (Chamomile)	-	ND	-	Halt, 1998
	FB <sub>1</sub> : 20-70,	-	-	Martins <i>et al.</i> , 2001b
	FB <sub>2</sub> : ND	-	-	Omurtag and Yazicioğlu, 2004
	ND	-	-	Santos <i>et al.</i> , 2009
	<LD-90.0	7.3-12.5	DON: 123.4-191.5, T2: 3.5-8.3	
<i>Melissa officinalis</i> (Lemon Balm)	-	ND	-	Halt, 1998
<i>Mentha</i> sp. (Spearmint)	<LD	2.1-9.3	DON: 46.9-91.1, T2: 3.9-4.9	Santos <i>et al.</i> , 2009
<i>Mentha piperita</i> (Peppermint)	FB <sub>1</sub> : 160, FB <sub>2</sub> : ND			Omurtag and Yazicioğlu, 2004
<i>Morus alba</i> (Weeping Mulberry)	-	ND	-	Halt, 1998
<i>Origanum vulgare</i> (Marjoram)	FB <sub>1</sub> : ND-<LD, FB <sub>2</sub> : ND	-	-	Omurtag and Yazicioğlu, 2004
<i>Olea europaea</i> (Olive leaves)	<LD	9.3-42.7	DON: 127.2-149.9, T2: 3.0-3.5	Santos <i>et al.</i> , 2009
<i>Peumus boldus</i> (Boldus)	<LD	7.0-10.3	DON: 223.1-343.5, T2: 21.9-26.7	Santos <i>et al.</i> , 2009

<i>Plantago lanceolata</i> (Ribgrass leaves)	<LD	1.6-7.7	DON: <LD, T2: 12.3-256.9	Santos <i>et al.</i> , 2009
<i>Rhamnus frangula</i> (Frangula bark)	<LD	1.5-44.1	DON: <LD-60.9, T2: <LD-12.6	Santos <i>et al.</i> , 2009
<i>Rheum officinalis</i> (Rhubarb stem)	<LD	3.1-24.4	DON: 58.4-241.8, T2:3.0-23.0	Santos <i>et al.</i> , 2009
<i>Rosa canina</i> (Rose hip)	ND	-	-	Omurtag and Yazicioğlu, 2004
<i>Salvia fruticosa</i> <i>Salvia officinalis</i> (Sage)	ND 130.0-133.3	- 4.7-5.2	- DON: 83.6-102.2, T2: 0.6-2.5	Omurtag and Yazicioğlu, 2004 Santos <i>et al.</i> , 2009
<i>Sambucus nigra</i> (Elder)	-	ND	-	Halt, 1998
<i>Sideritis libanotica</i> (Mountain tea)	ND	-	-	Omurtag and Yazicioğlu, 2004
<i>Silybum marianum</i> (St Mary's thistle seeds)	<LD-236.7	1.6-3.5	DON: <LD, T2: 17.5-35.6	Santos <i>et al.</i> , 2009
<i>Strychnos nux-vomica</i> (Nux vomica)	-	80	-	Roy and Chourasia, 1990b
<i>Taraxacum officinale</i> (Dandelion)	<LD	4.2-17.0	DON: 36.0-66.5, T2: 1.9-2.7	Santos <i>et al.</i> , 2009
<i>Tilia grandifolia</i> <i>Tilia</i> sp. (Linden)	- FB <sub>1</sub> : 20-200, FB <sub>2</sub> : ND FB <sub>1</sub> : ND-<LD, FB <sub>2</sub> : ND	ND - -	- - -	Halt, 1998 Martins <i>et al.</i> , 2001b Omurtag and Yazicioğlu, 2004
<i>Tribulus terrestris</i> (Small Caltrops)	-	20	-	Roy and Chourasia, 1990b
<i>Urtica</i> sp. (Nettle)	FB <sub>1</sub> : <LD-1487, FB <sub>2</sub> :ND-<LD	-	-	Omurtag and Yazicioğlu, 2004
<i>Valeriana officinalis</i> (Valerian root)	<LD-96.7	1.0-4.3	DON: 38.8-64.7, T2: 10.5-13.3	Santos <i>et al.</i> , 2009
<i>Verbena officinalis</i> (Vervain)	<LD	4.8-9.5	DON: <LD-60.0, T2: 4.7-20.4	Santos <i>et al.</i> , 2009
<i>Zea mays</i> (Corn silk)	FB <sub>1</sub> : 50-150, FB <sub>2</sub> : ND ND	- -	- -	Martins <i>et al.</i> , 2001b Omurtag and Yazicioğlu, 2004
<i>Zingiber officinale</i> (Ginger)	ND	ND	DON: 9, NIV: 34, NEO: 23, T2: 18	Patel <i>et al.</i> , 1996

(1): ND: not detected, <LD: lower than limit of detection, FB: fumonisin, DON: deoxynivalenol, NIV: nivalenol, NEO: neosolaniol, T2: T-2 toxin, FUS X: fusarenone X.

### Analytical Methods for Detection of Mycotoxins in Herbs

Mycotoxin contamination in natural samples is not homogeneous and sampling schemes must be based in official regulations like the EU regulation (EC, 2006b; EU, 2010b). EU official sampling and testing methods are available only for some commodities, and might not be applicable to herbal drugs without

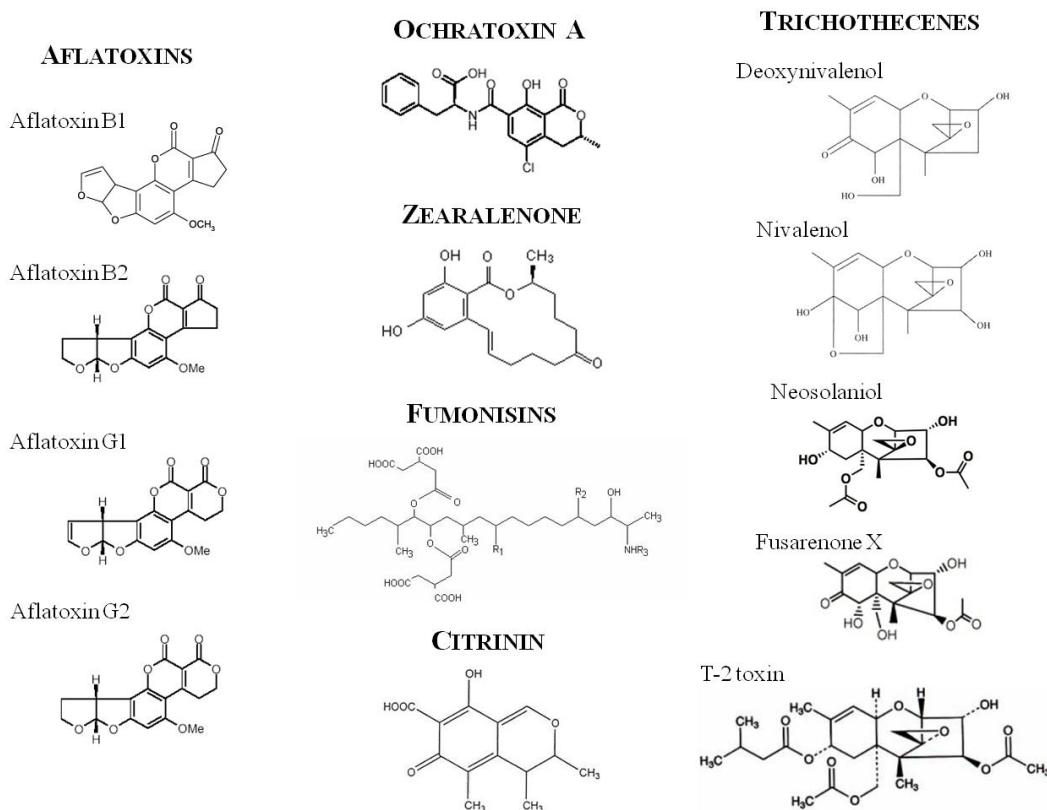
thorough adaptation and validation (Kabelitz and Sievers, 2004; EC, 2006b).

The efficacy of the mycotoxin detection methods depends on the matrix analyzed (MacDonald and Castle, 1996; Ventura *et al.*, 2004; Gómez-Catalán *et al.*, 2005; Ip and Che, 2006). Since herbal products are complex matrices consisting of various components which can interfere with mycotoxin quantification, it is necessary to choose an extraction

and clean-up method appropriate to reduce these interferences, in order to be able to make a realistic quantification of mycotoxins (MacDonald and Caslte, 1996; Ali *et al.*, 2005; Zhang *et al.*, 2005). The extraction solvents generally used are organic solvents pure or mixed with water, or pure water, depending on the mycotoxins to be extracted. The organic pure solvents usually used are: acetonitrile, chloroform and methanol. Because herbs are complex matrices sometimes extraction is also made with addition of Tween 20 (Ali *et al.*, 2005; Zhang *et al.*, 2005; Trucksees *et al.*, 2006), phosphate buffered saline solution (Ali *et al.*, 2005; Trucksees *et al.*, 2006), salted aqueous solution (e.g., sodium bicarbonate) (Bresch *et al.*, 2000; Ali *et al.*, 2005;

Ariño *et al.*, 2007) or with addition of a salt (e.g., sodium choride, potassium chloride) (Roy and Kumar, 1993; Tassaneeyakul *et al.*, 2004; Braga *et al.*, 2005; D'Ovidio *et al.*, 2006; Ip and Che, 2006; Sewran *et al.*, 2006; Trucksees *et al.*, 2006). The sample-to-extractant ratio is an important parameter because a higher ratio (more sample per solvent) results in more concentrated extracts which lead to a decreased limit of quantification (Arranz *et al.* 2006). For the selection of the extraction solvent it is necessary to consider the clean-up method to be used, because, for example, immunoaffinity columns (IAC) are very sensitive to some reagents (Gómez-Catalán *et al.*, 2005; Arranz *et al.*, 2006).

**Figure N° 1**  
**Mycotoxins found in herbal products**



Sometimes the problem of interfering compounds can be overcome using sophisticated clean-up methods or even a 2-step clean-up procedure (Ali *et al.*, 2005; Braga *et al.*, 2005). There are several clean-up methods, from liquid-liquid extraction (Roy and Kumar, 1993; Halt, 1998), solid phase extraction (Shank *et al.*, 1972; Patel *et al.*, 1996; Selim *et al.*, 1996; Ventura *et al.*, 2004), strong

anion exchange (SAX) cartridges (Patel *et al.*, 1996; Martins *et al.*, 2001b; Omurtag and Yaziciođlu, 2004), multifunctional columns (Ali *et al.*, 2005) to IAC (Reif and Metzger, 1995; MacDonald and Castle, 1996; Patel *et al.*, 1996; Bresch *et al.*, 2000; Tassaneeyakul *et al.*, 2004; Ali *et al.*, 2005; Braga *et al.*, 2005; Gómez-Catalán *et al.*, 2005; Zhang *et al.*, 2005; Arranz *et al.*, 2006; D'Ovidio *et al.*, 2006;

European Pharmacopeia, 2006; Ip and Che, 2006; Lino *et al.*, 2006; Sewran *et al.*, 2006; Trucksees *et al.*, 2006; Ariño *et al.*, 2007; Müller and Basedow, 2007; Romagnoli *et al.*, 2007). The most selective procedures are multifunctional columns and IAC. The efficacy of IAC clean-up for mycotoxins depends on the analyzed matrix (MacDonald and Castle, 1996; Ventura *et al.*, 2004).

Many analytical methods have been developed for mycotoxins in herbs which include thin layer chromatography (TLC) (Shank *et al.*, 1972; Roy *et al.*, 1988; Kumari *et al.*, 1989; Roy and Chourasia, 1989; Roy and Chourasia, 1990a; Roy and Chourasia, 1990b; Abeywickrama and Bean, 1991; Roy and Kumari, 1991; Kumar and Roy, 1993; Roy and Kumar, 1993; Halt, 1998; Fuat *et al.*, 2006), ELISA or other immunoaffinity-based methods, HPLC with fluorescence detection (Reif and Metzger, 1995; MacDonald and Castle, 1996; Patel *et al.*, 1996; Selim *et al.*, 1996; Martins *et al.*, 2001b; Omurtag and Yaziciođlu, 2004; Tassaneeyakul *et al.*, 2004; Ali *et al.*, 2005; Braga *et al.*, 2005; Gómez-Catalán *et al.*, 2005; Zhang *et al.*, 2005; Arranz *et al.*, 2006; D'Ovidio *et al.*, 2006; European Pharmacopeia, 2006; Ip and Che, 2006; Lino *et al.*, 2006; Sewran *et al.*, 2006; Trucksees *et al.*, 2006; Ariño *et al.*, 2007; Müller and Basedow, 2007; Romagnoli *et al.*, 2007), GC/MS (Patel *et al.*, 1996) or HPLC/MS (Bresch *et al.*, 2000; Ventura *et al.*, 2004).

For some mycotoxins like AFB<sub>1</sub>, AFG<sub>1</sub>, FBs and trichothecenes the sensitivity of the detection method can be improved including a sample derivatization step. Generally a pre-column derivatization with *o*-phtaldialdehyde solution is used for FBs (Patel *et al.*, 1996; Martins *et al.*, 2001b; Omurtag and Yaziciođlu, 2004; Sewran *et al.*, 2006). For trichothecenes, a pre-column derivatization using Trisil TBT is used (Patel *et al.*, 1996). Nowadays the best method for AF derivatization is post-column one, which can be made using pyridinium bromide perbromide (PBPB) (MacDonald and Castle, 1996; Patel *et al.*, 1996; Zhang *et al.*, 2005; Arranz *et al.*, 2006; European Pharmacopeia, 2006; Ip and Che, 2006; Sewran *et al.*, 2006), or preferably using a KOBRA cell (Reif and Metzger, 1995; Tassaneeyakul *et al.*, 2004; Gómez-Catalán *et al.*, 2005; Arranz *et al.*, 2006; D'Ovidio *et al.*, 2006; European Pharmacopeia, 2006; Müller and Basedow, 2007; Romagnoli *et al.*, 2007) or a photochemical reactor for enhanced detection (Ali *et al.*, 2005;

Arranz *et al.*, 2006; European Pharmacopeia, 2006; Trucksees *et al.*, 2006). The use of a pre-column derivatization with trifluoroacetic acid (TFA) (Ali *et al.*, 2005; D'Ovidio *et al.*, 2006; Trucksees *et al.*, 2006) or a post-derivatization using PBPB or KOBRA cell can be useful, but presents some problems related with the reagents purity, by-products formation, completeness of the reaction and stability of the reagent and products formed (Braga *et al.*, 2005). The AF derivatization with TFA can be also used to confirm the presence of AF in TLC determinations (Shank *et al.*, 1972; Roy *et al.*, 1988; Roy and Chourasia, 1989; Roy and Chourasia, 1990a; Roy and Chourasia, 1990b; Abeywickrama and Bean, 1991; Roy and Kumari, 1991; Kumar and Roy, 1993).

It should be borne in mind that there is not a universal method of analysis for each herb or herbal groups. For each analyzed herb a prior validation of the method should be made, to be sure that the mycotoxins under study are correctly quantified. Furthermore, depending on the analyzed matrix it is possible to have different interfering compounds which can elute at the same time as the mycotoxin of interest.

#### ACKNOWLEDGMENTS

The authors are grateful to the Spanish (Project AGL2007-66416-C05) and Catalanian (XaRTA-Reference Network on Food Technology) Government for their financial support. The authors would like to thank F. Correia for the grammatical review.

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