Journal of Stored Products and Postharvest Research Vol.4(1). pp.1 – 10, January 2013
Available online at http://www.academicjournals.org/JSPPR
DOI: 10.5897/JSPPR12.029
ISSN 2141-6567 ©2013 Academic Journals

Review

Plant secondary metabolites as source of postharvest disease management: An overview

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Accepted 2 January, 2013

Postharvest losses of stored products are enormous due to fungal deteriorations. Although, there are a number of synthetic fungicides available in the market for checking these deteriorations, they have several side effects such as high toxicity, long degradation periods, their residues in food chain, chronic poisoning through the continuous intake of small quantities, development of new races of pathogens, non-biodegradable nature and exhaustible source. Therefore, we must search the new sources of pesticides, which in addition to their efficiency, must be safe and selective to target specific pathogen. Plants are very rich sources of bioactive chemicals such as phenolics, polyphenols, quinones, flavones, flavonoids, flavonols, tannins, cumarins, terpenoids, lectins and polypeptides. Some plants yield fraction of essential oils, which have inhibitory effects on microorganisms. They are highly enriched with terpenoids. They are volatile, biodegradable, eco-friendly and are easily available in local environment. Several studies have been conducted on the use of such botanicals for controlling postharvest diseases, and hence, the present communication reviews the work done on investigating the fungitoxic potential of essential oils and extracts from higher plants in fungal deterioration of stored products.

Key words: Myotoxins, fungitoxic, biodeterioration.

INTRODUCTION

It is estimated that between 60 to 80% of all grains produced in the tropics is stored by farmers themselves. For small farmers, the main purpose of storing grains is to ensure household food supplies. It also provides a form of saving to cover future cash needs through sale or for barter or gift exchange. Small quantities of grains are also stored for seed purpose. Farmers who produce surplus may also store grains for sale later to take advantage of seasonal price rise.

Traditional storage systems must provide maximum protection against deterioration of commodity by inclement weather and pests. Farm storage systems have been developed to satisfy these requirements. Most of them are well adapted to their environment and losses are generally low, often below 5% of grain weight over a storage season (Tyler and Boxall, 1984). However, for resource, poor farmers even losses of this magnitude have important implications for food security. In addition to storage of food grains at farmer's level, thegovernments of different countries also procure and store them for reasons of food security for its growing population. There was spiral increase in populations of several countries including India. In case of India, it has crossed one billion marks in 2000A.D. and it will give India the dubious distinction of being the most populated country in the world by 2025A.D. Therefore, the challenge of feeding ever growing population shall be a very difficult task. We cannot meet such a challenge with the increase in food production alone but their protection from deterioration caused by fungi and other pests during storage have to be given due emphasis (Shukla, 1997).

In developing countries, the greatest losses during storage to cereals and other durable commodities are caused by fungal pests. Deteriorations due to fungi are due to unhygienic conditions of storage and this in turn is associated with initial high moisture content of the stored products or absorption of moisture during storage due to defects in the storage system (Stinson et al., 1980).

DETERIORATION IN STORED PRODUCTS BY PESTS

There are several storage fungal pests that cause deteriorations in stored commodities. The most common among them are - *Aspergillus flavus, A. niger, A. clavatus, A. terreus, A. versicolor, A. candidus, Alternaria alternata, Curvularia lunata, Cladosporium cladosporoides, C. herbarum, Epicoccum nigrum, Emericella nidulans, Emericella rugulosa, Fusarium acuminatum, F. moniliforme, Mucor hiemalis, Penicillium citrinum, P. chrysogenum, P. expansum, P. funiculosum, P. italicum, Rhizopus arrhizus, Rhizopus nigricans, Syncephalastrum racemosum* (Shukla, 1997; Shukla et al., 2000; Pandey, 2008; Shukla, 2010). Several of these fungal pests such as species of *Aspergillus, Penicillium, Fusarium, Alternaria* and *Cladosporium* etc. not only bring about deterioration in the quality and quantity of agricultural produce in storage and transit but they also create health hazards in animals and human beings by producing toxic metabolites in the form of mycotoxins in the stored commodities (Samson et al., 1995; Shaaya et al., 1997; Pandey, 2008).

These organisms are capable of growing under diverse conditions of moisture, pH and temperature. If the mould growth occurs, there is always the concomitant possibility of mycotoxin production (Zohri and Abdel-Gawad, 1993). Mycotoxins are dangerous chemicals that cause several complications in the body. They are carcinogenic, hepatoxic, nephrotoxic and teratogenic (Samson et al., 1995; Pandey, 2008). Extreme toxicity of mycotoxins lies in the fact that they are extremely stable and dangerous in minute quantities. Further, once formed, they cannot be removed from the commodity concerned by processing or removal of visible mould growth. They are heat stable, so they cannot be destroyed by cooking. Since mycotoxins are extremely toxic, regulatory and industry guidelines limit are set at very low levels. In developing countries, often the good quality products are exported while substandard produce unacceptable to foreign buyers (because they exceed regulatory limits for mycotoxin content) is sold to the domestic market (Dawson, 1991). Therefore, the mycotoxin contamination of food and feeds is not a particular problem to the developed world, although heavy economic costs are incurred in ensuring low concentrations of mycotoxins (Mannon and Johanson, 1985). In poorer developing countries, such contaminations have more serious consequences, affecting agricultural economies, reducing annual production and good quality exports and seriously affecting the health of the population. Therefore, the control measures for checking deterioration and mycotoxin production should be such that which occur naturally in the local environment; less toxic to environment, animal and human being and cost effective.

MANAGEMENT OF DETERIORATION CAUSED BY PESTS AND MYCOTOXIN PRODUCTION

To control fungal deterioration of agricultural produce, many organic and inorganic fungicides have been developed and used. The use of many of these has, however, been restricted due to their undesirable side effects such as a high and acute toxicity, the long degradation periods, their concentration in food chain, the suspected dangers of chronic poisoning through the continuous intake of small quantities (Samson et al., 1995; Kumar et al., 2007). Besides, due to development of new races of pathogens, many of these fungicides are gradually becoming out of date (Dikshit, 1980).

As such the development of new effective and harmless fungicides is needed on an increasing scale. According to Brandes (1967) much of our efforts are being wasted in routine testing of the standard fungicides, when there is a pressing need to investigate new sources of effective fungicides (Brandies, 1967).

Furthermore, the sources of these synthetic fungicides are largely petrochemicals which are exhaustible. Therefore, haunt for inexhaustible sources of such chemotherapeutants is highly desirable. Green plants appear to be the reservoir of effective chemotherapeutants and can provide reversible source of useful pesticides (Swaminathan, 1978). Tropical floras, in contrast to their temperate zone counterparts, have developed a more efficient and varied defense mechanism because of the far severe conditions for survival.

They, thus provide a rich and intriguing source for isolating natural secondary plant metabolites, which exhibit interesting antimicrobial properties. Although only some 15,000 secondary plant metabolites have been chemically identified, their total number may exceed 4,000,000 (Saxena, 1993).

They are vast cornucopia of defense chemicals. Recent reports on the possibility of use of higher plants and their constituents have indicated their usefulness in providing fungicides, which are largely non-phytotoxic, more systemic and easily biodegradable (Fawcett and Spencer, 1969; Beye, 1978). They are sustainable and can be continuously propagated year- after-year and do not have any negative impact on the environment as long as care is taken to avoid the propagation of plants from foreign ecosystems which might, therefore, become established as weeds.

Further, where plants are used as storage protectants, they are almost always applied to control insect pests. This is reflected in volumes of research directed to identifying insecticidal or insect repellent plants and plant extracts. Nevertheless, some work has been undertaken to determine whether plants can control storage fungi. Most workers have investigated the properties of spices as inhibiting agents of mycelial growth of *Aspergillus* species and of its toxin production.

Syzygium aromaticum (cloves) have been found to be particularly effective, often completely inhibiting both fungal growth and toxin production (Hitokoto et al., 1980; Mabrouk and El-Shayeb, 1980). Many commercially available spices and herbs, turmeric (*Curcuma* spp), basil (*Ocimum basilicum* L.), marjoram (*Marjorana hortensis* Moench.), anise (*Pimpenella anisum* L.), cumin (*Cuminum cyminum* L.) and coriander (*Coriandrum sativum* L.) are able to completely inhibit toxin production, but only partially inhibit fungal mycelial growth (Hitokoto et al., 1980). Aqueous extracts of weeds and medicinal plants have also been shown to inhibit toxin production by *Aspergillus flavus.*

These include *Ricinus communis, Arnebia nobilis* and *Nicotiana plumbaginifolia* (Bigrami et al., 1980). Other fungi, such as, *Fusarium solani, F. phaseoli* and *Verticillium albo-atrum,* have been shown to be susceptible to tannins extracted from bark of various trees, including chestnut and wattle (Lewis and Papavizas, 1967). In addition to above, several other fungi have been shown to be susceptible to essential oils extracted from higher plants (angiosperms and gymnosperms) (Table 1).

DISCUSSION

Several hundred-research papers are published each year on the antimicrobial activity or other functional activity of botanicals from higher plants, and a complete review of all of them is beyond the scope of this article. The most excellent ones are given above. A brief discussion on efficacy and application of antimicrobial botanicals from higher plants is given below. The antimicrobial botanicals which have the potential to be used as storage protectants can be divided into several useful categories, including phenolics, polyphenols, quinones, flavones, flavonoids, flavonols, tannins, cumarins, terpenoids, lectins and polypeptides (Cowan, 1999). Many herbs, such as thyme, contain multiple active compounds which represent different chemical families. The essential oil fraction of botanicals is often the inhibitoriest chemical fraction to growth and survival of microorganisms. Essential oils are highly enriched with terpenoids. Examples of herbs and spices containing terpenoids which have been shown to have antimicrobial activity include allspice, basil, bay, burdock, cinnamon, paprika, chilli pepper, clove, eucalyptus, dill, gotu kola, grape fruit seed extract, horseradish, lemon verbena, oregano, paod' arco, papaya, peppermint, rosemary, savory, sweet flag, tansy, tarragon, thyme, turmeric, valerian and willow (Duke,1985; Cate, 2000). The other major chemical group found in plants which has been frequently reported to have antimicrobial and antifungal activity is the sulfoxide/ isothiocyanate family, which includes onion, garlic, mustard and members of the *Brassica* family. Approximately 30% of essential oils which have been examined are inhibitory to bacteria, and more than 60% of essential oil derivatives have been shown to be inhibitory to fungi (Cowan, 1999; Chaurasi and Vyas, 1977; Shaaya et al., 1997; Shukla et al., 2000; Kumar et al., 2007; Pandey, 2008).

The mechanism of action for the antimicrobial activity of botanical storage protectants is not fully understood. However, terpenoids and phenolics are thought to exert inhibitory action against microorganisms by membrane disruption (Cichewick and Thorpe, 1996; Lambert et al., 2001; Schultes, 1978). Simple phenols and flavonoids appear to inhibit growth by binding to biochemicals essential for metabolism (Peres et al., 1997). Both coumarins and alkaloids are thought to inhibit growth of microorganisms at the genetic level (Hoult and Paya, 1996; Rahman and Chaudhary, 1995; Shukla, 2010).

Although numerous studies have been done *in vivo* to evaluate the antimicrobial activity of botanicals, only a few studies have been done with stored products for preventing or controlling mould growth. Inhibition of fungal growth on coriander and fennel seeds dressed with 0.5% concentration of *Cedrus* oil has been reported (Dikshit, 1980). Seeds of coriander showed good result when fumigated with essential oil from *Citrus media* and *Ocimum canum* at their MIC (Dubey et al., 1993). *In vivo*, application *Cymbopogon citratus* oil showed that growth of *Aspergillus flavus* was greatly checked (Mishra and Dubey, 1994). Seeds of wheat and groundnut fumigated with oil from *Eucalyptus citriodora* showed excellent result (Shukla, 1997). Oil and leaf powder of *Cymbopogon citratus* significantly reduced deterioration and aflatoxin production in shelled melon seeds inoculated with toxigenic *Aspergillus flavus, A. niger, A. tamarii* and *Penicillium citrinum.* Use of *Trachyspermum ammi* oil inhibits growth of dominant storage fungi such as spp. of *Aspergillus, Penicillium, Alternaria* etc. *in vivo* condition (Shahi et al., 2002; Shukla, 2010).

These studies show that some botanicals have the potential to be effective storage protectant although product development to optimize functionality and flavour will be challenging. More studies are needed on applications of botanicals from higher plants in storage protection to fully understand how best to optimize their use.

Use of many plants in storage protection is commonly Generally Recognized As Safe (GRAS) but some plants

Table 1. Effect of essential oils and extracts on stored pests and diseases.

Plant species and plant part used for extraction	Chief findings	Reference (s)
Oil from roots and flowers of *Raphanus sativus*	Effective against *Fusarium avenaceum, Phoma* spp. and *Alternaria brassicae*	Nehrash (1961)
Oil from *Juniperus communis*	Effective against *Aspergillus niger*	Slavenas and Razinskaite (1962)
Oil from *Mentha piperata* and *M. officinalis*	Both oils exhibited antimicrobial activity	Kovacs (1964)
Oil from *Mentha arvensis* var. *piperascens*	Oil of the plant from Formosa showed the highest antibacterial and antifungal activity	Sanyal and Verma (1969)
Some extracts and volatile oils.	Volatile oils showed much stronger fungicidal and fungstatic effect than the extracts	Cresan and Hodisan (1975)
Oils from *Cymbopogon citratus, Mentha arvensis* and Sweet basil	*Mentha arvensis* was effective against *Penicillium italicum* causing fruit rot of *Citrus reticulata*	Arora and Pandey (1976)
Oil from rhizome of *Curcuma angustifolia*	Effective against some saprophytes, plant pathogens and dermatophytes	Banerjee and Nigam (1977)
Oils from seeds of *Carum bulbocastanum, C. carvi, Trachyspermum ammi, T. roxburghinum, Cuminum cyminum, Nigella sativa,* leaves of *Psidium guajava* and galls of *Thuja orientalis*	All the oils except *Carum bulbocastanum* and *Psidium guajava* were found active against nine fungi and six bacteria	Nigam and Rao (1977)
Oils from *Cymbopogon citratus, C. martini, C. winterianus Ocimum basilicum, O. citriodorum, O. gratissimum* and *Mentha citrata*	Showed antifungal activity against *Penicillium notatum* and some derimatophytes	Sawhney et al. (1977)
Oil from *Nepeta hindostana*	Effective against *Aspergillus* and *Penicillium* spp	Sharma and Gautam (1977)
Oils from seeds of *Ammomum subulatum* and *Azadirachta indica,* from flower buds of *Sygygium aromaticum* and bulb of *Allium sativium.*	*Azadirachta indica* and *Allium sativum* possessed good antifungal activity against eight species of fungi	Thind and Dahiya (1977)
Oil from seeds of *Lantana camara*	Effective against *Curvularia lunata, Fusarium oxysporum* and some other fungi	Avadhoot and Verma (1978)
Oils from *Piper nigrum, Avapana triplinerve,* and *Mentha arvensis*	Antifungal activity of the oil was investigated against *Curvularia lunata, Rhizopus* spp., *Aspergillus* spp., and *Penicillium* spp. Oil from *M. arvensis* inhibited the growth of all fungi. Oils from *P. nigrum* and *A. triplinerve* were inactive against *A. fumigatus* and *P. decumbens*	Chaurasia and Kher (1978)
Oil from *Cedrus deodara* roots	Showed antifungal response against the fungi tested	Dikshit et al. (1978)
Oils from *Cinnamomum tamala* leaves, *Boswellia serrata* and *Nardostachys jatamansi.*	Showed antifungal activity against several fungi	Girgune et al. (1978)
Oils from *Aster thomsoni, A. peduncularis, Cymbopogon jwarancusa, Selinum tenuifolium*	Showed antifungal activity against five fungi with varying sensitivity. Oil of *C. jwarancusa* exhibited the best response	Mathela and Sinha (1978)
Oils from *Ageratum conyzoides, Feronia elephantum* and *Blumea membranosa*	Oil of *B. membranosa* exhibited the strongest toxicity as compared to other two oils against storage fungi	Sharma et al. (1978)
Oil from *Cymbopogon martini* var. *sofia*	Effective against *Helminthosporium oryzae* at 0.7% and also toxic to 15 other fungi tested	Singh et al. (1978)
Oil of *Mentha arvensis var. piperascens*	Strong antifungal activity against 17 out of 23 fungi tested; and was more active than some fungicides tested	Singh et al. (1978)
Oils from leaves of *Caesalpinia sappan*	Strong efficacy against *Aspergillus nidulans*	Yadava et al. (1978)
Oil from seeds of *Nigella sativa*	Showed antifungal activity against *Aspergillus* spp. and *Curvularia lunata*	Agrawal et al. (1979)
Oil from leaves of *Adinocalymma allicea*	Effective against *Helminthosporium oryzae* at 500 ppm, killed 12 fungi out of 21 tested and proved to be non-phytotoxic to host; and much more active than some	Chaturvedi (1979)

Table 1. Contd**.**

	commercial fungicides tested	
Oil from *Blumea membranacea*	Fungitoxic against *Cladosporium cladosporoides, Aspergillus sydowi* and *A. luchuensis* while in effective against *Fusarium oxysporum*	Geda and Bokadia (1979)
Oils from leaves of *Abutilon indicum, Bothriochloa pertusa, Murraya exotica* and *Dalbergia sisso.*	Only the oils of *A. indicum* and *Bothriochloa pertusa* showed fungitoxicity.	Jain et al. (1979)
Oils from tuber of *Cyperus scariosus* and leaves of *Ocimum basilicum*	Oil of *C. scariosus* was more active than that of *O. basilicum* against certain bacteria and various fungi	Lahariya and Rao (1979)
Oils from *Anethum graveolens, Apium graveolens, Carum carvi, Coriandrum, sativum, Cuminum cyminum, Foeniculum vulgare, Oenanthe stolonifera, Trachyspermum ammi, Parthenium hysterophorus, Eupatrium ayapana, Clerodendron interme, Lantana camara, Psoralea corylifolia, Zingiber officinale and Cymbopogon martini.*	Oils of *T. ammi, O. stolonifera, Anethum graveolens, Apium graveolens, P. hysterophorus* and *P. corylifolia* showed significant antifungal activity against all the fungi tested	Sharma and Singh (1979b)
Oil from seeds of *Oenanthe javanica*	Effective against *Aspergillus fumigatus, A. nidulans, Trichothecium roseum Microsporum gypseum, M. cocci.*	Sharma and Singh (1979a)
Oils from *Cinnamomum camphora, Eucalyptus camaldullensis, Ocimum kilimandscharicum* and *Valeriana wallichii*	Showed antifungal activity against certain plant & human pathogen	Suri and Thind (1979)
Oil from leaves of *Eucalyptus citriodora*	Effective against *A. niger* and *Clathridium corticola* at 1:1000 dilutions	Suri et al. (1979)
Oil from the leaves of *Cestrum diurnum*	Fungicidal activity against *Rhizoctonia solani* at MIC of 0.7%. At this concentration it exhibited the mycelial growth of all the 39 fungi tested indicating thereby wide range of activity	Renu et al (1980)
Oil from *Cymbopogon martini, C. oliveri var. rosasofia, Trachyspermum ammi* (dethymelated oil) and *Ocimum kilimandschericum* (Campherized oil)	All the oils showed wide range of activity (except Campherized oil) and were more active than some synthetic fungicides	Singh et al. (1980)
The volatile fractions of leaves of 131 species of higher plants were screened. The oil of *Peperomia pellucida* was found to exhibit the strongest fungitoxicity against *Helminthosporium oryzae.*	The MIC of the *P. pellucida* oil against *Helminthosporium oryzae* was 2000 ppm at which it showed broad fungitoxic spectrum, quick in killing activity,heavy inoculum density themostable, nonphytotoxic, non systemic, and self life up to 150 days. It also prevents the appearance of disease during preliminary *in vivo* testing	Singh (1980)
Different parts of 15 angiospermic plants were screened. The volatile oil extracted from the rhizomes of *Alpinia galanga* showed the highest fungitoxicity.	Oil showed highest fungitoxicity against *Helminthosporium oryzae.* The MIC was 0.4% of the medium. The oil was as fungitoxic as quintozene and Zeneb and gave more inhibition of *H. oryzae* than dinocap and Copper oxychloride. The oil was also fungitoxic against *Alternaria alternata, Aspergillus flavus, A. fumigatus, A. niger* and *Pestilotia* spp.	Tripathi (1980)
Essential oils and extracts from seeds of *Putranjiva roxburghi.*	Oil was effective against broad spectrum of storage fungal pests. It was thermostable and remained toxic for at least 150 days	Saxena (1980)
Oil from leaves of *Ocimum canum*	The oil at 3000 ppm exhibited broad range of activity inhibiting all the 31 fungi tested	Bhargava et al. (1981)
Oil from leaves of *Ocimum canum*	Showed fungitoxicity against *Aspergillus flavus, A. vesicolor* and number of other fungi	Dubey et al. (1981)
Oil from fruits of *Cinamomum cecidodaphne*	Showed fungitoxicity against all the storage fungi tested.	Chandra et al. (1982)
Essential oils from epicarp of *Citrus medica*	Showed fungitoxicity against *A. flavus, A. vesicolor* and several other storage fungi. The oil was thermostable and broad spectrum	Dubey et al. (1982)
Oil from epicarp of *Citrus medica* and leaves of	Showed toxicity against *A. flavus* and *A. vesicolor* and	Dubey et al.

Table 1. Contd**.**

Ocimum canum	many other storage fung	(1983)
Oil from leaves of *Schinus molle*	Showed toxicity against *A. flavus, Alternaria alternata, Penicillium italicum.* Oil was thermostable and toxicity lasts for at least 12 months, the maximum time taken into consideration	Dikshit et al (1986)
Oil from Pericarp of *Prunus persica*	Showed toxicity against all the storage fungal pests tested	Mishra and Dubey (1990)
Oil from epicarp of *Citrus sinensis*	Showed fungitoxicity against some important storage fungi tested	Singh et al. (1993)
Oil from leaves of *Cymbopogon citratus*	Showed toxicity against *A. flavus, A. niger* and many other storage fungi	Misra and Dubey (1994)
Essential oils from *Eucalyptus citriodora, E. dalarympleana, E. labeopinea, E. pauciflora*	Oil at 1000 ppm showed complete inhibition of *Penicillium italicum.* The oil of E. *dalarympleana* and *E. laveopinea* showed fungistatic activity against the test fungus at 3000 ppm; but the oil of *E. laveopinea* showed partial inhibition at 3000 ppm. The oil of *E. citriodora* at 1000 ppm exhibited fungicidal nature and withstood heavy inoculum	Shahi et al. (1997)
Essential oils from leaves of *Melaleuca alternifolia* and *Monarda citriodora* var. *citriodora.*	Showed fungitoxicity against several storage fungi tested	Bishop and Thornton (1997)
Essential oil from leaves of *Callistimon lanceolatus*	Showed fungitoxicity against A. *flavus, A. niger* and many other storage fungi	Mishra et al. (1997)
The oil from leaves of *Cymbopogon flexuosus*	Effective against *Aspergillus flavus, Penicillium italicum* and *Alternaria alternata.* The oil showed broad spectrum, inhibited heavy doses of inocula, thermostable and toxicity persisted for at least 12 months	Shukla et al. (2000)
Oil from leaves of *Ocimum sanctum* and *O. gratissimum*	*Ocimum sanctum* showed absolute toxicity against *A. flavus* but was moderately active against A*. niger.* However, *O. gratissimum* was found to exhibit absolute toxicity against both the tested fungi	Sharma (2001)
The oil from epicarp of *Citrus sinensis*	Oil exhibited strong fungitoxicity at 0.5% concentration against *A. flavus, P. italicum* and *Alternaria alternata* as a contact toxicant and inhibited heavy doses of inocula with quick killing action. The pesticidal action of the oil was thermostable up to 80℃ and lasted even up to 24 months with broad spectrum	Shukla et al. (2000)
Oil from the flower buds of *Eugenia caryophylata* (clove).	Clove oleoresin at 0.2 to 0.8% (v/v) was tested against *Candida albicans, Pencillium citrinum, Aspergillus niger* and *Trichophyton mentagrophytes* and was highly effective against *T. Mentagrophytes* and *Candida albicans, however, P. citrinum* and *A. niger* were relatively more resistant. Clove oleoresin was first dispersing in sugar solution and then used for antifungal testing	Nunez et al. (2001)
Oil from leaves of *Cymbopogon flexuosus.*	MIC was 0.2 µl/ml against *Alternaria alternate* 0.4 µl/ml against *A. flavus, A. fumigatus, A. parasiticus, Cladosporium cladosporoides, P. italicum, P. digitatum;* and 0.5 µl/ml against *Borytis cyneria and Helminthosporium oryzae.* The efficacy persists broad spectrum, thermostable, self life up to 48 months. The oil was used for in *vivo* controlling post harvest spoilage of *Malus pumilo*	Shahi et al. (2002b)
Essential oil extracted from leaves of *Eucalyptus pauciflora*	MIC was 0.3, 0.4, 0.5 and 0.6% against *Alternaria, Aspergillus, Penicillium,* and *Rhizopus* respectively	Shahi et al. (2002a)
Oil from aerial parts of *Ammoides pusilla*.	Oil showed antimicrobial activity against eight strains of bacteria, several fungi and yeast such as *Aspergillus*	Laouer et al. (2003)

Table 1. Contd**.**

	niger and *Candida albicans.* GC and GC/MS of oil showed 46 constituents among which thymol (44.5%), Y-terpinene (32.9%) and p- cymene (13.5%) were the chief	
Oil extracted from dried, crushed flowering plants of *Thymus serpyllum*	Oil showed antifungal properties against *A. flavus, A. awamori, A. niger, A. foetidus* and *A. oryzae.* It also inhibited all the three stages of asexual reproduction, that is, spore germination, mycelial growth and spore formation	Rahman (2003)
Essential oil and phenolic extracts of *Dinnetia tripetala* (pepperfruit)	Oil and phenolic extracts inhibited growth of several food borne microorganisms including *Penicillium* spp. and *Aspergillus* spp. etc.	Ejechi and Akpomedaye (2005)
Oil from *Lippia alba, Lippia microphylla, Citrus lemon, Cymbopogon citratus* and the phytochemicals citral, eugenol and mircene	Oil as well as phytochemicals showed significant antimould activity. Among the products that evidenced the antimould activity citral and eugenol showed the lowest minimum inhibitory concentration which was 1% and 4% respectively. The mould strains assayed are *Fusarium* spp. *Rhizopus* spp. *Aspergillus flavus, A. niger* and *Penicillium* spp.	de Souza et al. (2005)
Oil from seeds of *Cuminum cyminum* (cumin)	Oil contained more than 60 compound principal among them were cumin aldehyde (36 %), β-pinene (19.3%), P-cymine (18.4%) and Y-terpinene (15.3%). Antimicrobial testing showed high activity against *A. niger*, the Gram+ bacteria *Bacillus subtils and Staphylococcus epidermidis* as well as the yeast *Saccharomyces cereviceae* and *C. albicans*	Jirovetz et al. (2005)
Oil of cinnamon bark (*Cinnamomum zeylanicum*)	The oil contained 61% cinnamaldehyde, 29% cinnamic acid, and two minor unidentified compounds. The oil's efficacy at 300 and 100 µl/l completely inhibits the growth of *A. flavus* and *A. ruber* respectively	Jham et al. (2005)
Oil of *Foeniculum vulgare* sp. *piperitum*	The GC-MS of the oils showed estragole (53.08, 56.11 and 61.08%), fenchone (13.53, 19.18 and 23.46), and α-phellandrene (5.77%, 3.30%, and 0.72%), respectively. Strong antifungal property against *Alternaria alternata*, *Fusarium oxysporum*, and *Rhizoctonia solani* at 40 ppm.	Ozcan et al. (2006)
Five essential oils viz., thyme, sage, nutmeg, eucalyptus and cassia	The cassia oil inhibited completely the growth of *Alternaria alternate* at 300 to 500 ppm, while, the thyme oil exhibited a lower degree of inhibition 62.0% at 500 ppm, only	Feng and Zheng (2007)
Essential oil from the leaves of *Chenopodium ambrosioides* Linn	The oil completely inhibited the mycelial growth of *Aspergillus flavus* Link. at 100 µ/ml. Further, the oil exhibited broad fungitoxic spectrum against *Aspergillus niger, A. fumigatus, Botryodiplodia theobromae, Fusarium oxysporum, Sclerotium rolfsii, Macrophomina phaseolina, Cladosporium cladosporioides, Helminthosporium oryzae and Pythium debaryanum* at 100 µg/ml	Kumar et al. (2007)
The oil of *Putranjiva roxburghii* exhibited the greatest toxicity	The oil was found to be fungicidal and thermostable against *A. flavus* and *A.niger*, at its minimum inhibitory concentration (MIC) of 400 ppm	Tripathi and Kumar (2007)
The essential oils of oregano (Origanum vulgare), thyme (*Thymus vulgaris*) and clove (*Syzygium aromaticum*)	Oregano essential oil showed the highest inhibition of mold growth, followed by clove and thyme. *A. flavus* was more sensitive to thyme essential oil than *A. niger.* Clove essential oil was a stronger inhibitor against *A. niger* than against *A. flavus.*	Viuda et al. (2007)
The essential oil of *Citrus medica* L.	The oil exhibited a wide spectrum of fungitoxicity, inhibiting all 14 fungus species of *Arachis hypogea*	Pandey (2008)

Table 1. Contd.

The essential oil of *Cymbopogon flexuosus*, *Trachyspermum ammi* and their active constituents	Oil of *C. flexuosus* and its major constituents Citral 38% and Geraniol 24.56% as well as oil of *T. ammi* and its constituents Thymol 80.7%, ρ-cymene 11.4% and α-pinene 7.9% were found effective against *A. flavus* and *Penecillium italicum*	Shukla (2010)

contain noxious compounds, which may render them unsafe for both animals and humans to consume. Toxicology axiom." The dose makes the poison" also apply in some cases. It means that a substance that is safely consumed in the diet at low levels may be unsafe if consumed at a higher level in the diet. Therefore, the data demonstrating that the botanical is safe when consumed at the higher level is needed. And it is virtually difficult to find typical toxicological data such as Acceptable Daily Intake and No Effect Level. Further, here may be unusual sensitivities of some parts of the population to specific herbal compounds or strong aromatic ingredients. Therefore, while using botanicals in storage protection, these points should be duly emphasized to avoid negative nutritional or health consequences.

Conclusion

A small number of antimicrobial agents have been used for many years with little expansion, and there is a real need to expand the list of storage protectants which can be used to ensure safety and quality of stored products. These systems may have synergistic or additive uses with one another or may also be used with conventional antimicrobial compounds. The future of naturally occuring antimicrobial system seems be sure, as new storage protection systems are being rapidly developed and used in a variety of storage products.

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