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A Review on Antifungal Green Preservatives: An Aspect of Food Industry

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Abstract

Many studies have been conducted on the harmful effect of mycotoxins on human and animal health. However, other chemicals can also contribute to the toxicity of ingested foods, directly or indirectly (via animal products). Many synthetic chemicals that are used for field treatments of cereals, or applied during storage time to prolong the storage time and to insure the absence of fungal contamination, are proven to be harmful to human and animal health. In order to reduce the usage of such chemicals and to improve the already deteriorated ecosystems, scholars are dedicated to optimizing and commercializing a “greener” option not only for agronomic applications, but also for the food industry. Recent advances in the effectiveness of green preservatives aiming at the food industry will be described in this paper. The intention is to preserve not only the health-related aspects of food by applying green preservatives, but also to maintain the ecological aspect regarding the environment as much as possible.

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Introduction

A better yield, pathogen resistance and nutritive value of crops are the main goals of agriculture. However, cereals are susceptible to various pathogens that can deteriorate all of the above-mentioned characteristics. Fungi are resilient microorganisms and omnipresent on many foodstuffs, starting from raw materials to the final product. They can survive the different process conditions (pressure, temperature, humidity) and unit operations and negatively affect the shelf life of food. Besides the shelf life, fungi commonly affect and deteriorate the nutritive and safety aspect of contaminated foodstuff. In many cases, food is no longer suitable for consumption and needs to be destroyed. According to Sadiq *et al.,*[1] approximately 5-10% of foodstuff in the world and 50% of fruits and vegetables in tropical areas get discarded annually due to fungal

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spoilage. Another aspect of fungal contamination is toxic secondary metabolites and mycotoxins. Many of them are known and are regulated via different regulatory agencies (EFSA, WHO). The usual mycotoxins are aflatoxins, ochratoxins, fumonisins,[2,3] deoxynivalenol, zearalenone, etc., and they are designated to cause acute or chronic health deterioration in both humans and animals.[4–8]

Mycotoxin contamination of crops results in sometimes heavy economic losses due to the lower quality and additional expenses to achieve the desired product quality. The use of synthetic chemicals does improve the yield and its quality, but the general effect it has on the environment is nowadays beginning to be less acceptable. In addition, there is an increased demand from the consumers to use chemical-free commodities.[9–12] To reduce the application of chemicals in the environment and during food processing, the idea of biological agents has been on many minds and a topic of much research by eminent scholars.

An effective approach for the suppression of mycotoxins in foods is the application of plant extracts, well- investigated compounds for this purpose that are mostly essential oils (EO’s). Bioactive compounds from plants are acceptable antifungal agents and their efficacy has been reported in many scientific papers.[13–27] Compounds from Spanish paprika act oppressively on A. *parasiticus* and P. *nordicum* and subsequent production of AFB1, AFG1, and OTA. As reported by several researchers, the addition of 2%–3% of Spanish paprika in meat products inhibits AF and OTA synthesis.[16] Similar research conducted by (add author name)[17] investigated the influence of capsaicin on OTA production in grapes by *Aspergillus* section *Nigri* and by *Aspergillus carbonarius.* (add authors’ names)[18] evaluated the efficiency of cinnamon, clove, lemongrass, oregano and palmarosa EOs on maize kernels infected with *Fusariumproliferatum*. They also evaluated the subsequent fumonisin B1 (FB1) production and discovered that at 0.995 aw, all EOs showed satisfactory efficiency at 20 and 30°C. However, lower aw at 30°C proved to inhibit the activity of all essential oils while at 20°C. Cinnamon, clove and oregano oils still exhibited certain activity against F. proliferatum. FB1 synthesis was suppressed by cinnamon, oregano, and palmarosa oils at 0.995 aw at both temperatures. Lower aw blocked the inhibitory effect of EOs on the synthesis of FB1. Similar studies reported the inhibitory effects of clove and cinnamon oils on the proliferation of *Aspergillus* flavus and aflatoxin production[18–21] in maize. Cinnamon and clove oils were proven to be effective in suppressing the aflatoxin production by *A. flavus*.[21] Oregano oil was also reportedly successful in suppressing *A. flavus*, *Aspergillus* ochraceus, and *A. niger*.[24,25] It showed certain inhibitory effects for fungal species found in wheat.[25](Add authors’ names)[26] investigated the effect of palmarosa oil against 12 fungi. (add author here)[27] successfully suppressed the growth of *Fusariumgraminearum* on chicken and pig feed by using different concentrations of butylated hydroxyanisole, propylparaben and thymol. However, the downside of EOs application in the food industry is that they usually result in impaired sensory properties since they have a strong aroma, so the dosage should be optimized in order to achieve the wanted preservative effect and to avoid the impairment of sensory properties. This can be achieved by using novel methods of application of EOs, such as encapsulation or nano encapsulation.[19,28–30] EOs have been declared as GRAS (generally recognized as safe) and are approved by the European Union for application in foods.[31] An overview of potential green agents that can be utilized as preservatives in the food industry is shown in Table 1.

This paper will sum up some of the current studies on the application of green preservatives against mycotoxigenic fungi in the food and feed industry. The preservation of food from mycotoxins is as important as the secondary effect of the application of green preservatives, and that is the preservation of ecological systems directly involved in growing crops and food production (water, soil, air).

Processed Food Protection

Dairy Products

EOs effectively suppress the proliferation of many microorganisms but also enhance the antioxidant activity, which makes them suitable for application in dairy products.[32] They are commonly added to dairy products to add flavor and aroma, but they also have a preservative role. When combined in a starch-based coating applied to cheddar cheese, linalool, carvacrol and thymol exhibit inhibitory properties against *A. niger*.[33] Application of oregano EO via nanoemulsions suppresses the proliferation of Staphylococcus aureus during 15 days of storage at 4°C.

There is much other research regarding the addition of EOs to dairy products, but they mostly revolve around the suppression of bacterial population in dairy products, which is not the topic of this review.

Table 1: An overview of potential antifungal natural products that can be utilized as preservatives in food industry

Commodity		Protective agent	Suppressed species	Effect	Source
Cereals					
	maize	cinnamon, clove, lemongrass, oregano, and palmarosa EO	F. *proliferatum*	suppresses FB1 production	18
		clove and cinnamon oils	A. *flavus*	suppresses AF production	18-21
	wheat	oregano oil	A. *flavus*, A. *ochraceus*, and A. *niger*	suppresses fungal growth	24,25
Dairy products	cheddar cheese	linalool, carvacrol and thymol	A. *niger*		33
		oregano	S. aureus		
Meat products		Spanish paprika	A. *parasiticus* and P. *nordicum*	suppresses production of AFB1, AFG1, and OTA	16
		thyme, cinnamon, rosemary, and garlic	microbial growth	suppresses fungal growth	30
Fruits and vegetables	grapes	capsaicin	A. section *Nigri* and A. *carbonarius*	suppresses production of OTA	17
		A.*nilagirica* EO		prolonged shelf-life	53
	chili seeds and fruits	citral, citronella, citronellol, eugenol, farnesol, and nerol	fungi	antifungal	43
	mandarines	A.conyzoides EO	blue mold	prolonged storage time	44
	bananas	C. nardus,	anthracnose	suppresses	45

		C. flexuosus, and O.basilicum EO		fungal growth	
		cinnamon EO	fungi	suppresses fungal growth	46
	M. pumilo	C. flexuosus EO	rotting	suppresses rotting	47
	groundnut	P. roxburghii EO	A. *flavus* and A. *niger*	suppresses fungal growth	41
		C. pendulous EO		suppresses microbial growth /deterioration	48
	papaya fruit	T. capitate and C. aurantifolia EO		suppresses microbial growth /deterioration	49
	Buchanania	O. canum EO		prolonged shelf-life	50
	pigeon pea seeds	C. pentaphylla and C. ambrosioides EO	A. *flavus*, A. *niger*, A. *ochraceus*, and A. terreus	prolonged shelf-life	51,52
	V.radiate	L. alba EO	fungi	suppresses AF production	54
Dried fruits	A. occidentale L., P. amygdalus Batsch, V. vinifera L., B. lanzan Spreng, A.s hypogaea L., P. dactylifera L. and C. nucifera L.	O. basilicum EO	A. *flavus* fungal growth	suppresses	55
Spices		H. aromatica EO	Aspergillus *flavus*	suppresses fungal growth	60

Meat Products

Essential oils have been used in the preservation of food for a very long time. Herbs and spices were known not only for their preservative properties, but for being able to improve the undesirable aromas of spoiled foods, especially meat and meat products. Representing an important source of nutrients due to their high-quality protein content, essential amino acids, B-group vitamins, minerals and other nutrients, meat and meat products are an important commodity in the food industry. Since it is so rich in nutrients and contains high levels of water, meat is susceptible to spoilage.[34] Health trends impose the application of natural agents to ensure food safety. In meat preservation, the plant extracts, EOs, have shown to be potent antimicrobial agents against spoilage. Here too, due to the intense aroma and smell, the application of EOs is somewhat limited, but the application can be optimized to improve the microbial stability and sensory quality as well.[35] Encapsulation of EOs is an effective way to remove or reduce to a minimum the organoleptic impairment EOs cause in practice.[30] Certain EOs (thyme, cinnamon, rosemary and garlic) proved to have strong antimicrobial activity individually and in combination.[30] Many papers investigated the effectiveness of EOs against the spoilage of bacteria on meat, but there are not many studies that refer to the antifungal antimycotoxin effect of plant extracts on meat products. This topic should be explored since fungal species have been found on meat products.[36–40]

Fruits and Vegetables

Fruits and vegetables are also highly susceptible to spoilage. However, many studies have been carried out where the use of EOs proved to enhance the shelf-life of fruits and vegetables.[41,42] Research by Tripathi *et al.*[43] showed that fungal infection can be suppressed for 6 months by applying citral, citronella, citronellol, eugenol, farnesol and nerol to chili seeds and fruits. Blue mold that can infect mandarins can be reduced by using the essential oil from *Ageratumconyzoides.* This also increased the storage time by up to 30 days.[44] *Cymbopogonnardus*, *C. flexuosus* and *Ocimumbasilicum* exhibited potential as suppressants for anthracnose in bananas. They showed an increased banana storage time by up to 21 days as well.[45] Cinnamon EO prolonged the shelf life of bananas up to 28 days and protected the fruit against fungal deterioration.[46] Positive results were achieved when using *Cymbopogon flexuosus* EO to reduce rotting of Maluspumilo up to 3 weeks.[47]

Another approach, using fumigation with EOs from *Putranjivaroxburghii,* was proven to be successful in controlling *A. flavus* and *A. niger* on groundnuts through the storage time. This too increased the storage time of this commodity by up to 6 months.[41] Also applied during fumigation, the EO from *Cymbopogon pendulous* acted protective on groundnut and prolonged its storage time by 6–12 months.[48] EOs from *Thymus capitate* and *Citrus aurantifolia* decreased the outbreak of deterioration in papaya fruit.[49] Application of Ocimumcanum EO as a seed dressing and fumigating agent prolonged storage time of *Bhuchanania*.[50] Fumigation with *Clausenapentaphylla* and *Chenopodiumam brosioides* EOs acted protectively on pigeon pea seeds and successfully suppressed the occurrence of *A. flavus*, *A. niger*, *A. ochraceus*, and *A. terreus* up to 6 months.[51,52] Applied fumigation with Artemisia nilagirica EO increased the storage time of table grapes by up to 9 days.[53] Lippia alba EO also showed suppressive properties toward fungi and aflatoxin production in *Vignaradiata*. Storage time was prolonged to 6 months.[54]

Dried Fruits

Due to their high nutritive value but lower moisture content, dried fruits are somewhat less susceptible to fungal proliferation. However, the incidence is much higher in tropical and humid places.[55] In a study[56] conducted, *Ocimumbasilicum* EO was used as a green preservative for dried fruits (*Anacardiumoccidentale* L., *Prunusamygdalus Batsch*, *Vitisvinifera* L., *Buchananialanzan Spreng*, *Arachishypogaea* L., *Phoenix dactylifera* L. and *Cocos nucifera* L.). The EO of O. *basilicum* showed strong toxicity against the toxigenic strain of *A. flavus* when used as a fumigant and should be considered for practical application.

Spices

Spices have a long history in human consumption. They are aromatic parts of different plants such as the root, seed, leaves, bark, flower, bulb and fruit.[57] Spices commonly hold antimicrobial and antioxidant properties. Some exhibit analgesic, antipyretic, hepato protective, carminative, anticarcinogenic, antidiabetic and anti-inflammatory properties[58,59] but are still susceptible to fungal proliferation and mycotoxins contamination.[60] According to RASFF[61] spices are designated as a commodity that can be highly contaminated with fungal toxins such as aflatoxins, citrinin, fumonisins, zearalenone, sterigmatocystin, tenuazonic, alternariol and deoxynivalenol. A study[60] where they used nanoencapsulated *Homalomena aromatica* EO and applied it as a green preservative against toxigenic *Aspergillus* flavus strain (AF-LHP-NS 7), storage fungi, AFB1 and free radical-mediated decay of stored spices. The investigation showed that this EO could be a potent green preservative in the preservation and prolongation of storage time for certain spices.

The application of green preservatives is getting more attention from scholars, growers and customers who demand chemical-free foods. However, there are still not many papers describing this particular topic of antifungal natural products. Many microorganisms are involved in the food industry, and the search for a suitable and efficient green agent against contamination demands a significant effort from multidisciplinary (food engineers, chemists, botanists) scholars.

Conclusions

Microbial contamination often purports the presence of various toxins which very often act detrimental to human and animal health. The detriment of plant material commonly results in lower nutritive value. There are many different natural bioactive chemicals that can be employed as suppressors of microbial proliferation and, subsequently, mycotoxin contaminations of plant-originating raw materials. Cereals, dairy, meat products, fruits and vegetables, spices and feed are all submissive to microbial contamination. Employment of essential oils or other natural chemicals from plants (terpenoids, sesquiterpenoids, phenolics) has proven to be an efficient bioweapon against various fungal infections. Traditional methods of application now can be improved by modern, more approachable methods (i.e. nanoencapsulation of essential oils into carbohydrate and protein polymers). Many studies are devoted to finding the best green option for improving the health of consumers, ensuring the safety of commodities and replacing synthetic preservatives with more eco-friendly versions.

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Conflict of Interest

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