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Novel Strategies to Mitigate Mycotoxin Contamination in Raw Medicinal Plant Materials

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ABSTRACT

Present article elucidates the published literature regarding microbial contamination of raw medicinal plant materials and decontamination/detoxification strategies of mycotoxins due to their harmful impacts on human health. Mycotoxins extant a great concern to raw medicinal plants due to their inimical health and socio-economic collision. To overcome the fiscal losses and health issues associated with mycotoxin contagion of raw medicinal plants, several novel innovative techniques have been used to remove the mycotoxin without affecting the people health, product quality and their nutritional potential. Thus, mitigation of mycotoxins can be attained by several physical, chemical and biological approaches, using *Lactobacillus, Streptococcus, Pediococcus* and other lactic acid bacteria, Actinomycetes, yeasts, molds and other relevant methods including the use of enzymes and phytochemicals. A wide range of phytochemicals accompanied with plant essential oils have been found effective against several mycotoxigenic fungi in contaminated raw medicinal plants. These green preservatives are safe, bio-degradable and eco-friendly in nature. Now a days, detoxification by nanoparticles is one of the promising approaches has been adopted due to its high disinfection effects, and these perspectives are influential against mycotoxin contamination via an irreversible process. The aim of this review is to systematically understand the problem of mycological assessment, mycotoxin contamination and their mitigation in raw medicinal plants by using effective botanicals.

Keywords: Bio-formulation; Essential oils; Mycotoxin mitigation; Medicinal plant materials; Postharvest management

1. INTRODUCTION

Phytotherapy is a branch of science that deals with plants either to cure ailments or as health-ameliorating agents. These herbal formulations are crude preparations of dried plants or any plant part like leaf, stem, root, flower, or seed. In present times, the use of herbal products proliferates in developing countries, in the faith that it is natural, safe and harmless[1]. At the time of harvesting and post-harvest storage, raw medicinal plant gets contaminated by various toxigenic soil fungi[2]. Among them *Aspergillus, Penicillium* and *Fusarium* spp. has been recognized as the most frequent and dominant ones, responsible for the production of mycotoxins, these secondary metabolites are the main cause of severe toxicity, like carcinogenicity, neurotoxicity, teratogenicity and immunotoxicity etc. resulting the major problems in tropical and sub-tropical regions, because environment favors the fungal growth and toxin production due to high temperature and moisture contents[3]. Recently 400 different mycotoxins have been recognized, and scientific attention is focused mainly on aflatoxins (AF), ochratoxin (OTA), fumonisin (FUM), zearalenone (ZEA), and deoxynivalenol (DON) due to their high prevalence and economic losses (Fig.1).

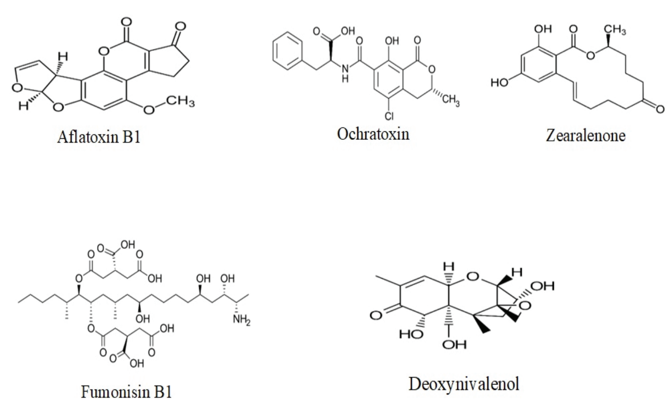

Figure 1. Chemical structures of major mycotoxins.

Since a long period, considerable research efforts are directed to enhance mitigation policies based on risk management, risk assessment, eradication, interruption and remediation policies for several mycotoxins, along with good agricultural practices, storage and transportation cannot completely prevent mycotoxin presence in the medicinal plants such as pepper (*Piper* L. spp.), sweet pepper (*Capsicum* L. spp.), turmeric (*Curcuma longa* L.), nutmeg (*Myristica fragrans* Houtt.) and ginger (*Zingiber offi cinale*)[1]. Decontamination strategies to manage and

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mitigate mycotoxin in medicinal and aromatic plants have been introduced are technologically diverse and classified as physical, chemical and biological method. Physical measures of mitigation involve cleaning, sorting, milling, dehulling, UV light treatment, cold plasma treatment and irradiation treatment. Some adsorbents or binders like activated charcoal, zeolites, bentonite and sepiolite clay are effectively used in removal of fungal toxins. However, specific strategies such as execution costs, poor adsorption, residual toxicity and less specificity against the mycotoxins still hinder their routine application[4].

Mycotoxin mitigation leads to decontamination and detoxification process of medicinal plants may be performed by different means, as shown in Fig.2. Majorly conventional fungicides have been used to remove mycotoxin contamination in raw medicinal plants, including application of ammonia, hydrochloric acid, sodium hydroxide, butylated hydoxyxyanisole, butylated hydroxytoluene and oltipraz[5]. These chemicals are non-friendly as well as their inaptness in mitigation of mycotoxins is also seen and high chemical application is restricted because of residual toxicity, environmental concerns and public health hazard[6]. Therefore, biological control remains the most prominent method for the degression of fungal toxins into harmless byproducts by micro-organisms. Microbiological methods including probiotic bacteria, yeasts and their enzymes, having nature of decontamination of mycotoxin in medicinal plants[7].

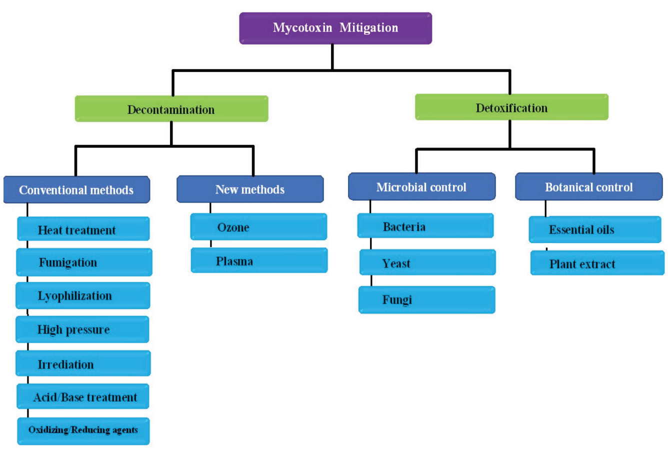

Figure 2. Decontamination and detoxification methods for mycotoxin mitigation.

Thus, keeping this in mind there is a demand to develop possible strategies which can prevents fungal deterioration of several medicinal plants and modified the toxic mycotoxin residues to harmless forms without any limitations[8]. Accordingly, need of an alternative essential oil- based bio preservative which is safe, biodegradable and eco-friendly in nature. In order to enhance the durability of essential oils due to it's volatile nature, requirement of green, sustainable and eco-friendly Nano-emulsion bio-preservative formulations can be. Botanicals (essential oils and some plant extracts) are the best alternatives as biofungicides for decontaminating mycotoxicosis and other fungal infections. Recent research has been done on the applicability of plant-based products, such as bio-fungicide and nutraceuticals to overcome the prevalence of toxic fungi and toxin production, the most common contaminants of raw medicinal plant materials are *Aspergillus* and *Penicillium* genera producing aflatoxins, an important carcinogen[9].

2. MITIGATION OF MYCOTOXIN FROM RAW MEDICINAL PLANTS

In order to mitigate mycotoxin contamination, several approaches have been tried including Good Agricultural Practices (GAPs), ailment management, and proper storage circumstances. Adequate processing of foods can further limit mycotoxins by physical reduction and by other measures like, chemical decontamination, enzymatic transformation of fungal toxins into least toxic products[5]. The control of mycotoxin defilement in agriculturally important items are immense cause of worry worldwide which led to several control strategies like prevention, detoxification, and decontamination of mycotoxins in both pre and post-harvest conditions. Thus, the aim of this review is to present an overview of the measures of prevention and detoxification of medicinal plant materials from mycotoxins in due course of partially reduce or totally mitigate them.

2.1 Pre-Harvest Strategies

Good agricultural practices, good manufacturing strategies, proper environmental factors, and good storage conditions are the appropriate strategies for pre-harvest prevention. In GAPs, the implementation of a crop rotation program, use of suitable fungicides, herbicides and insecticides for the prevention of fungal contamination, weed eradication, and insect damage, seed treatment, soil analysis are included and to lowers the mycotoxin contamination also improves the genetic composition of the selected commodities[10]. Among the environmental factors, temperature and humidity play the greatest role in production of mycotoxin on mycotoxigenic fungi, also favorable storage conditions, moisture content, temperature and humidity of store houses are the concern for fungal proliferation and toxin contamination[11].

2.2 Post-Harvest Strategies

In the field as well as storage condition, spoilage and mycotoxin contamination of agricultural commodities or medicinal plants have been reported. However, pre-harvest measures do not appropriate for mitigation of mycotoxin in raw medicinal plants. Thus, post-harvest management can affect concentration of fungal toxins in raw materials by physical removal, chemical transformation, enzymatic detoxification, and adsorption to solid[5]. It was reported that, naturally mycotoxins can be mitigated by thermal induction, radiation management, and cold-plasma treatment chemical methods includes reduction, oxidation, alcoholysis, hydrolysis, absorption, and microbial agents are used in biological methods[12].

2.2.1 Physical Treatment

Physical methods, applied to eliminate mycotoxins are sorting, milling, dehulling and UV light, irradiation as well as cold plasma, including adsorbents or mycotoxin binders (activated charcoal, zeolites, bentonite and sepiolite clay). However eventual residual toxicity, implementation costs, dearth adsorption and selective action against various mycotoxins may cause difficulties in their routine application[4]. (Table1) shows some examples concerned to fungal decontamination of medicinal plant stuffs and their products via several physical methods.

2.2.1.1 Sorting

This technique is used since last of the 19th century, based on particle size and weight[23]. Undoubtedly, sorting, washing, or milling constitute the first processing step of natural disinfection of agricultural commodities after harvest. Reports show that, this is the superior technique having no risk of producing waste products[24].

2.2.1.2 Processing

By using processing technique, one can lower the concentration of mycotoxins, but cannot totally mitigate[25]. Two parameters, temperature along with time also affecting the mycotoxin level of the end product. However, fungal toxins are heat tolerant, some traditional practices at high temperature more than 100ºC may help to lowers specific mycotoxins. During extrusion process, heat and water content of the materials lowers aflatoxin level by fifty to eighty percent[26].

Table 1. Several decontaminating strategies accessible in former literature

Techniques	Commodities	Results	References
Dried heat treatments / Steaming	Licorice root powder (*Glycyrrhiza glabra*)	Heating or steaming may cause change in colour and lowers sugar reduction, glysyrryzin constituents, and pH, while increases the total sugar and viscosity of root extract.	13
Freeze-drying	Lemon balm Essential oil (*Melissa officinalis*)	The attribute and amount of the essential oil will not change, because of using relevant temperature. A very short period of time for drying is taken by oven which is cost effective in compare to shade method.	14
	Brown seaweed (*S. hemiphyllum*)	It is one of the relevant drying technique to maintain the nutritional value of S. hemiphyllum.	15
High hydrostatic pressure	Aloevera gel (*Aloe barbadensis Mill.*)	This pressure best functioning at 500 MPa/5 min to ensure the preservation of major compatible property of Aloevera gel along with antioxidant, antimicrobial and physico-chemical value.	16
High pressure technology	Herbal plants liquor	This technique favourably banished the microbial load like yeast, moulds and other bacterial contamination in both processed and infusion forms.	17
Gamma irradiation	Guggul (*Commiphora mukul*), Gulvel (*Tinospora cordifolia*) Chirata (*Swertia chirayita*), and different natural formulations	10 kGy Irradiation dose was reported as adequate and safe for mitigating total microbial load without lowering its nutritional and medicinal value.	18
	Clove (*Syzygium aromaticum*), Harad (*Terminalia chebula*) and Turmeric (*Curcuma longa*)	For manufacturing medicines, 5kGy Irradiation dose was sufficient to sterilize the material while the total decontamination was found at 10 kGy, irradiation dose.	19
Electron beam treatment	Chyavanaprash is an ayurvedic natural formulation	According to WHO, 2.5 kGy - 5 kGy dose of irradiation is sufficient to limit mycotoxin at permissible level which don't has any considerable change in physical, sensory and chemical attributes.	20
Ozone treatment	Cardamom seeds (*Elettaria cardamomum* (L.)	After treatment with ozone, cardamom extract was tested by free radical scavenging property and found effective ferric-reducing antioxidant property. Although total polyphenol and antioxidant content were same.	21
Plasma treatment	Red pepper (*C. annuum* L.)	Plasma therapy effectively inhibited A. flavus, also heat and cold plasma treatment lowers B. cereus spores synergistically. Additionally cold plasma application is effective for red pepper powder including various powder formulations to enhancing their shelf life and safety measures.	22

2.2.1.3 Storage

Proper storage environments play major contribution in reducing fungitoxins because they affect the gross production of molds. Mainly temperature and high humidity enhance the production of mycotoxins and mold growth. In good storage environments, like proper packaging, good ventilations, appropriate temperature and humidity can lowers the proliferation of molds and production of mycotoxins[27]. In evoluting countries because of bad storage conditions, 20% -50% harvest loss were reported[25].

2.2.1.4 Irradiation

On an industrial scale, it can be an approach for reducing mycotoxins and strengthen both the plant components and adulterator: reacts and modify the texture of components. Radiation is mainly two types either ionizing (gamma) or non-ionizing (solar, UV, microwave), which usually lowers or mitigate toxic microbes along with mycotoxins in medicinal aromatic plants28.

2.2.1.5 Cold Plasma

After mid-1990s, this technique has been in use to deactivate microorganisms. To decontaminate microorganisms of medicinal aromatic plants cold plasma method has been successfully recruited, is a relatively fast, environmentally friendly, and less temperature consuming method[22]. The technique of Cold atmospheric pressure plasma (CAPP), is used for decontamination of mycotoxins because it is cost-effective and environment friendly, after treatment for 8 min, significant reduction in mycotoxins reported (93% reduction in AFs, 100% in ZEA, 93% in FUs and 90% in TCs)[29]. However, cold plasma has some negative impact like poor penetration capacity chiefly on solid foods and not available at commercial scale. In addition, there is very less information is available that how it affects the quality and quantity of active substances of the product[30].

2.2.1.6 Mycotoxin Binders

This is a physical technique, mainly used in human intervention and also in decontaminated feed. Activated charcoal and bentonite respectively used to mitigate mycotoxins, mycotoxin binders get binds to mycotoxins and lowers the absorption of mycotoxin and check their entry into bloodstreams from the gut. Activated carbons, cholesterol, aluminosilicates and complex non-digestible carbohydrates are the various known absorbent[31]. This is a substitute for the fungal reduction of aflatoxins by physical means, modification in chemical structure directly affect the microbial enzyme thus cleavage of lactone ring reduces the toxicity of AFs[32].

2.2.2 Chemical Treatment

Mycotoxins have been removed chemically by reacting with materials and the reactions are induced by heat and acid-base environments. These methods were more effective in the reduction of molds growth and associated mycotoxin production during pre and post-harvest conditions of stored commodities[10].To mitigate mycotoxins, several chemical were used such as hydrochloric acid, ammonia, sodium hydroxide, butylated hydoxyxyanisole, butylated hydroxytoluene and oltipraz[5]. However, their extreme use is still restricted because of the residual toxicity, public health concern and environmental hazard[6].

2.2.2.1 Acid Treatment

A study showed that most common mycotoxins are developed resistance against weak acids. However, strong acids are effective against aflatoxins, destroyed the toxicity of AFB1 and AFG1 by modifying their chemical structure into hemiacetal forms AFB2a and AFG2a, respectively[33]. In addition, diluted citric acid, acetic acid and lactic acid were used for the treatment of aflatoxins under simulating cooking conditions and found lactic acid was the most potent one. Small carboxylic acid inhibits toxic fungal growth, apart from detoxifying mycotoxins these are used as preservatives[34].

2.2.2.2 Base Treatment

Under alkaline conditions, aflatoxins were found unstable. In this study showed that, NaOH and other alkaline reagents such as Na_2CO_3, Na_3PO_4, $Ca(OH)_2$, CH_3NH_2, $C_2H_5ONH_2$ and $C_2H_4(NH_2)_2$ found effective against mitigation of aflatoxins in groundnut, cottonseed meal and in corn. As detoxifying agent ammonia has been found extensively effective in both *in-vitro* and *in-vivo* experiments for degradation of AFs[35]. In contaminated oil, NaOH and KOH are generally used for aflatoxin degradation, while these are the secondary contaminant having harmful effects and reduced the nutritional value of the product[36].

2.2.2.3 Treatment with Oxidizing Agents

Ozonation is a technology, which is safe to use and also disinfect cereals, fruits and vegetables, and detoxify the mycotoxins. Several studies showed that ozone (O_3) is used in degradation of many mycotoxins. It is reported that, after treatment with 33 and 66 mg/l ozone for 1 hour, respectively degraded 80 and 93% of AFB1 in paprika[37]. In addition, several mycotoxins such as DON and moniliformin were degraded after the exposure of ozone[38]. At commercial scale for detoxification of aflatoxins, hydrogen peroxide (H_2O_2) was used. Figs were treated with H_2O_2 at 0.2% for 72 h of storage and reduced up to 66% of AFB1. Aqueous solution of H_2O_2 found effective against ZEA toxicity and lowers their concentration after treatment[39]. In addition, ammonium persulfate was used to oxidize ZEN and destroyed their toxicity[40].

2.2.2.4 Treatment with Reducing Agents

Sodium bisulfate was reported for the degradation of mycotoxins, mainly aflatoxin B1 (AFB1) in stored dried figs. Dried figs were spiked are exposed with 1% aqueous solution of sodium bisulfite for 72h at 25°C are sufficient to degrade 28% of the AFB1 (250 μg/kg) and after 1h heat treatment at 45°C to 65°C of bisulfite treated samples are degraded AFB1 up to 68 %[39]. Later, a review is available on various application of sulfur reagents to mitigate DON, produced 3 another DON sulfonates having equivalent mass and structural formula. At alkaline pH, DON sulfonates 1 and 2 intensely produced while at acidic pH, DON sulfonate 3 were formed slowly, irrespective of the sulfur reagent used[41].

Moreover, physical and chemical methods have several limitations; they are time-consuming, causes nutrient loss, inefficient, and costly appliance are needed. In proportion, microbial and botanical systems are safe and less hazardous, shown to be more specialized, more effective, and eco-friendly.

2.2.3. Biological Control

In the last two decades, several biological agents were searched for mycotoxin detoxification by various investigators, they grouped together by apart backgrounds and research erudition and put huge accomplishment in this research[42]. In the degradation of mycotoxins in medicinal plant materials, several microorganisms such as bacteria, fungi and yeast were used as microbial antagonists. These antipathetics has various action mechanism including competition and antibiosis for food as well as home. Biological control is an alternative approach for detoxification of mycotoxins, leading to production of lesser or complete elimination of toxic products. In vitro, pure microbial strains were used for the degradation of fungal toxins[43].

2.2.3.1 Bacteria

Several bacteria have been used as mycotoxin binders in medicinal plant materials. *Enterococcus faecium*, degraded AFB1 through ligating to the cell wall constituents of the bacteria. Another study showed that in microorganisms, bacterial polysaccharide (peptidoglycan) of cell walls were the binding sites for mycotoxins. To overcome the post-harvest loss of Indian gooseberry, preharvest treatment of amla with *Lactobacillus acidophilus* exhibited positive result against *P. funiculosum* in amla fruits[44]. In addition, Lactic acid bacteria (*Lactobacillus reuteri* and *Lactobacillus casei*) were also found effective to bind mycotoxins in aqueous solutions. Both, *L. amylovorus* and *L. rhamnosus* proved the effective binding up to sixty percent of AFs, presented its efficiency to binding several dietetic pollutants, in in-vitro experiments[45].

2.2.3.2 Yeast

Yeast was used as biological control agents (BCAs) against mycotoxin infection. It is widely used as biological control agents because producing antimicrobial compounds which has good impact on human and animals, and also are able to produce various substrates in bioreactors. Yeast don't produce allergens and secondary metabolites; unlike several filamentous fungi and bacterial antagonists[46].

2.2.3.3 Fungi

In starvation conditions, fungi have the capability of degradation and used the degraded products as a source of energy. Thus, fungi have the ability to produce aflatoxins and also their degradation[45]. Several species of fungi were used in detoxification of mycotoxins. Some of them are *Aspergillus, Trichoderma, Penicillium, Rhizopus* and *Clonostachys* spp[47]. The biological control of aflatoxins in corn is done by reactance with safe strains in both east and west Africa. *A. flavus* and *A. parasiticus* are non-toxic strains which are used in soil rhizosphere and they compete with other toxic strains[43].

2.2.4 Enzymatic Detoxification

Chemical and biological processing is combines with the enzymatic detoxification of mycotoxins. Enzymatic detoxification is specialized and showed high performance, it is safe to organisms when applied under mild condition. As we know that, enzymes are good catalysts and play role in non-stoichiometric ratios of mycotoxins[12]. For the mitigation of fumonisins, produced by *Fusarium*, some *Aspergillus* species producing enzyme were used. However, for the enzymatic detoxification of aflatoxins, enzyme such as microbial manganese peroxide, catalase, oxidase and laccase enzymes are used[43,26].

2.2.5 Novel Detoxification Strategies

Due to high recurrence of toxin producing fungal contamination there is need of consistent evaluation of bioactive botanicals and plant derivatives which is used as alternatives to conventional fungicides because they have high antifungal and anti-mycotoxigenic properties. Table 2 briefly describes some botanicals having antifungal properties and their mechanism of action, by interrupting the pathway of mycotoxin biosynthesis. Nowadays, nano-encapsulation formulations are also on trend and synergistically used with botanicals exhibited less side effect. That's why the natural formulations, used as antimycotic agents should be safe, efficacious, and have environment friendly attributes against fungi and their mycotoxins[48].

2.2.5.1 Botanical Management

Due the health hazard and socio-economic impacts of mycotoxins, it is being the great concern to food security and safety. Thus, here is a need to develop novel strategies that can mitigate the mycotoxin contamination of medicinal plant commodities without affecting the public health, nutritional value and bioactive components of the plants. Since pre-historic times, conventional medicine and agro-food science have profited by using plant-based compounds, such as EO's to inhibit various diseases and preserve food. In nature EO's may be subjected to protecting plant from biotic and abiotic pathogens[55]. Essential oils are volatiles obtained from different parts of aromatic plants, extracted by hydro-distillation using Clevenger's apparatus. Mishra et al. (2013) reported, the antimycotic property of 14 EOs constituents and its combinations forbids the proliferation of mycotoxigenic fungi. *A. flavus* was isolated by deteriorating raw herbal

Table 2. Antifungal effects of botanicals, their main constituents, and mode of action against mycotoxigenic fungi

Botanicals	Protective agents	Mycotoxigenic fungi	Mode of action	References
Turmeric (*Curcuma longa* L.)	Active constituent is curcumin	*Fusarium solani, Aspergillus flavus, & A. Parasiticus, Candida albicans, Penicillium expansum etc.*	Cell-death occur by means of apoptosis, necrosis, or autophagy.	49,50
Ginger (*Curcuma amada* L.)	Potent agent is α-zingiberene, 6-gingerol and 6-shogaol	*Fusarium. verticillioides, Aspergillus flavus, & Aspergillus parasiticus*	Exhibited Anti-fungitoxic properties by membrane degrading and preventing ergosterol biosynthesis.	9
Essential oil of *Rosmarinus officinalis* L.	Active components are 1,8-cineole, α-pinene & camphor	*Aspergillus flavus*	Inhibit ergosterol biosynthesis and lowers the mass of fungal hyphae.	51
Clove (*Syzygium aromaticum* L.)	Active constituents Eugenol, Eugenyl acetate, & β-caryophyllen	*Aspergillus flavus*	Enhance early apoptosis led to cell death by nuclear compaction and late apoptosis though membrane degradation of mycelium.	52
Camellia sinensis L. (Green tea)	Epigallocatechin 3-Ogallate (EGCG)	*Candida spp*	Cell membrane degradation causes osmotic imbalance leads to cell death.	53
Black pepper (*Piper nigrum* L.)	Potent aliment is Limonene, β-caryophyllene & sabinene,	*Fusarium oxysporum & Aspergillus niger*	Inhibited ergosterol biosynthesis through degradation of cell wall & plasma membrane, cytoplasm gets congested and damage cell components .	54

material of *Asparagus racemosus* and this plant-based preservative (EO) was used for enhancing the self-life of herbal material[56]. In addition, Antifungal properties of some botanical have been reported, *Syzygium aromaticum* (L.) having antifungal potential against several known fungal pathogen of plants and animals respectively, *Fusarium oxysporum* MTCC 284, *Fusarium moniliforme* NCIM 1100, *Aspergillus sp., Trichophyton rubrum, Mucor sp.,* and *Microsporum gypseum*. These fungal isolates were inhibited by the essential oil when examined by agar well diffusion method[57]. For mitigating the toxigenic fungi and mycotoxins, usually botanicals were used are considered to safe for humans and eco-friendly as compared to chemical treatment. It was reported that Aspergillus growth and AFB1 production was inhibited by using clove oil having its major component eugenol and also turmeric essential oils[11]. EOs has antibacterial, antifungal and insect repellent properties. So, these oils were used as alternative at the place of synthetic chemicals because botanicals are health safe and biodegradable in nature.

2.2.5.2 Bioformulation: Nano-Emulsion

In order to enhance the durability of essential oils due to its volatile nature, requirement of green, efficient and eco-friendly fungicide formulations is needed. A new-innovation particularly the Nano-emulsion originated, edible-oils are able in increasing the sustainability at the time of application, exhibiting a safe and efficient pesticide for pest control and disease management[58].

Nano-encapsulated EOs are more effective as compare to un-encapsulated form because of their large surface area to volume ratio which facilitate easy penetration into pathogen and inhibits the release of aroma. A sustainable formulation of Lavandin essential oil is used as biocide has been studied. Particle encapsulation of Lavandin oil is done by using high pressure spray procedure (PGSS) which was a biodegradable polymer. Both OSA (n-octenyl succinic anhydride (OSAN)-modifide starch and PEG (polyethylene glycol) were used for encapsulation, the efficiency of lavandin EO higher for PEG microcapsules obtained by PGSS[59]. This is reported that, micro-encapsulations are generally applicable for making durable fragrances, skin softener, phase-change materials, antimicrobial agents and drug-delivery system on to textile materials. Rosemary oil was encapsulated in ethylcellulose (EC) microcapsules through phase separation method, which was evaluated by Scanning Electron Microscopy and Confocal Laser Scanning Microscopy[60]. Hop essential oil nanoemulsion (HEO) not only inhibited spore germination and mycelial growth of *Fusarium graminearum,* causal organism of Fusarium head blight in paddy crop, but also reduced the production of mycotoxin deoxynivalenol (at 750 μg of HEO/g rice)[61]. *However,* Clove oil nanoemulsion effectively inhibited (at concentrations of 5000 ppm was 82.2%) the growth of *Neoscytalidium dimidiatum* a phytopathogen, infected the *Carum carvi* L. plant[62].

Several studies showed the mitigation of fungitoxins by adding nanoparticles as the efficient adsorbents of mycotoxins. For AFB1 detoxification, magnetic carbon nanoparticles are used. PAT decontamination was done by chitosan-coated Fe_3O_4 nanoparticles and decontamination of *Fusarium* spp. and their important fungal toxins were reported by silver nanoparticles[11].

3. CONCLUSION

In times to comes alternative medicine is going to gain more exposure and popularity for various human ailment and for its nutraceutical value. Production of medicinal plants, its processing, storage and uses is gaining importance with a commercial perspective globally and is a multibillion market which will further grow. Thus, protection of harvested raw medicinal products and assurance of its quality are the greatest concern to minimize storage losses as well as to establish efficacy and viability of products. There is a lot of storage fungi like *Aspergillus* sp., *Fusarium* sp., *Penicillium* sp. etc., are the major mycotoxin producing fungi, produces aflatoxin, ochratoxin, fumonisin, zearalenone, deoxynivalenol etc., degraded the bioactive components of medicinally important herbal raw medicinal plants. On seeing its major long term health hazards, there is need of possible fungitoxin mitigation techniques is proved as boon in field of herbal medicinal plants, traditionally used plants essential oils and their bioactive components containing terpenoids, sesquiterpenoids, and phenolics are widely acknowledged as decontaminating agents against fungal and mycotoxin contaminations of raw medicinal plant materials. A novel technological approach is currently on trend, nano-encapsulation of essential oils into various polysaccharides have been used to enhance their efficacy and shelf life of the formulation of green origin as an effective tool in commanding biodeterioration of raw medicinal plant materials under postharvest storage condition.

Such innovations will not only enhance the shelf-life of the medicinal plants in sustainable manner but also reduce dependency on synthetic pesticides which are harmful in many aspects. This approach will allow to develop innovative strategies of mycotoxin management which will enhance the economy of the herbal industry and the potent formulation will be proceed for registration, toxicity test and commercialization among the herbal industries.

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