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Review

Efficacy of plant-derived pesticides in the control of myco-induced postharvest rots of tubers and agricultural products: A review

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ABSTRACT

The most important losses in agricultural production which involve the greatest costs on the farm economy occur postharvest. It is estimated that worldwide between 10 and 40% losses of agricultural produce occur postharvest. Losses are more severe in developing than developed nations of the world. Several species of fungi and in some cases bacteria participate in postharvest deterioration and rots of tubers and agro-produce. These include species of *Aspergillus, Fusarium, Colletotrichum, Macrophomina, Penicillium* and *Rhizopus* amongst several others. In a bid to control these storage diseases several control techniques including physical, biological, and chemical and in recent times plant-based pesticides are employed. Chemical control has been identified as the most popular and most effective means of controlling plant diseases. However, it is being de-emphasized due largely to mammalian toxicity occasioned by chemical residues in crops. This in addition to many other demerits on ecological health and build-up of pathogens' resistance to some of the most effective fungicides have prompted search for alternatives. Recently in plant pathology many tropical plants are being screened for fungitoxic properties. This review presents highlights of the different control techniques and emphasized the efficacy of plant-based pesticides for control of myco-induced storage rots of tubers and agricultural products in the tropics.

Keywords: Rots, postharvest spoilage, fungitoxicity, plant-based pesticides, *Aspergillus, Fusarium.*

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INTRODUCTION

One of the most pressing problems facing the countries of the third world is food scarcity. It is reported that nearly 1 billion people are challenged by severe hunger in these nations of which 10% actually die from hunger-related complications. A substantial part of this hunger problem stems from inadequate agricultural storage and produce preservation from microbes-induced spoilages (Salami and Popoola, 2007; Kana et al., 2012). According to Arya (2010), of all losses caused by plant diseases, those that occur after harvest are the most costly. Cassava, yam and sweet potato are important sources of food in the tropics. Others are cocoyam, rice, maize, wheat, sorghum, millet and various fruits, legumes and vegetables. Cassava (Euphobiaceae; *Manihot esculentus*), is the third largest source of food carbohydrates in the world, providing a basic diet for more than 500 million people. Statistics show that 230 million MT of its tubers were produced in 2008 with Nigeria being its largest producer (Okigbo et al., 2009a). According to Amadioha and Markson (2007a) cassava has been prepared into 20 different forms in Africa including *garri, fufu, lafun*, and unfermented bread in the Americas. In Vietnam and Thailand the tubers are processed into ethanol, animal feed and starch for various industries (Okigbo et al., 2009c). The crop is drought-tolerant and provides a wide harvesting window which makes it act as a famine reserve. However, post-harvest deteriorations caused by microbial invasion of the tubers are the most important causes of loss in its production and contribute hugely to the unsuccessful long-term storage of the root tubers (Amadioha and Markson, 2007a, 2007b; Okigbo et al., 2009a). These pathogenic organisms gain entry into tubers probably through the area where the tubers are separated from the stems at harvest or the root tips which break during harvesting, or other natural openings and cracks on the tubers surfaces sustained during harvesting, transit or storage (Okigbo et al., 2009a). Nigeria is the world's largest producer of yam (Dioscoreaceae; *Dioscorea* spp.) producing 35.017 million MT of the tubers annually (Kleih et al., 2012). Postharvest deterioration and rot caused by various microorganisms is seen as the single most important factor militating against commercial yam production in Nigeria besides lack of research for development and capacity building in yam-based researches (Taiga, 2011; Onyeka et al., 2011). Rots according to Taiga (2011) result in loss of 7 million MT of yams annually. Rot of yam tubers may be soft, wet or dry and could occur pre- or post-harvest. Pre-harvest rots are due to infection of tubers by soil-borne pathogens. Generally, rotting starts from the field and progressed in storage. Postharvest fungal rots are up to 10% in yams (Ikotun, 1986). However, recent survey of three agriculturally important yam species in storage (*D. cayenensis, Dioscorea rotundata* and *D. alata*) in Umudike Southeast Nigeria, established mean fungi-induced rots ranging between 37.5 and 40% amongst the species (Ndubuisi, 2010). This may aggravate to 50% in some instances (Okigbo, 2005; Okigbo et al., 2009b) especially now given the challenge of climate change (Sadiku and Sadiku, 2011). Nahunnaro (2008) pointed out that Rots are exacerbated by high ambient temperatures and relative humidity. Soft rot caused by species of *Aspergillus, Botrydiplodia* and *Fusarium* result in tissue discolouration and production of foul smell from rotted tubers (Okigbo et al., 2009b). Sweet Potato (Convolvulaceae; *Ipomea batatas*) is another important food crop in Nigeria ranking third amongst important tuber crops of sub-saharan Africa (SSA) after yam and cassava (Amienyo and Ataga, 2007); with 100 million MT produced annually (Ewell and Matuura, 1991; Nwokocha, 1992). The crop according to Oladoye et al. (2013) is an important source of anthocyanidines and antioxidants. It can be incorporated with yam to make *Amala* and pounded yam. Rots pose serious problems to its production especially in vegetable potato. In Iran, survey showed that up to 10% pre-harvest and 20% post-harvest rots occurred in the crop (Bidarigh et al., 2012).These rots constitute major impediments to the drives for food security in Nigeria. Cocoyam (Araceae; *Colocasia esculentus*) is one of the important crops in Nigeria. Nigeria leads its production with 3.7 million MT per annum. The crop is grown as a staple in African, Oceanic and Asian cultures. Cocoyams are rich in carbohydrates, vitamins (especially vitamin B6), minerals, trace elements and fibre while the leaves contain vitamins A and C. These make it popular amongst diabetics. Its nutritional values compare well with potatoes (Talwana, 2009). Cocoyams are used in much the same way as yams being processed into *fufu*, chips and different kinds of Nigerian cuisines etc. Current yield levels of the cocoyam production are low on a worldwide basis. The most mentioned disease symptoms on the crop in wetlands of East Africa were tuber rot, smelly tubers and sticky ooze from the tubers (Talwana, 2009). In Nigeria, the crop is seriously affected by tuber rot (*Sclerotium rolfsii*). Attacks from this disease caused a drop in production figures of cocoyam by 11% (Nwachukwu and Osuji, 2008). According to Ijato et al. (2011), worldwide, 129.7 million MT of tomato (Solanaceae; *Lycopersicum esculentus*) fruits are produced annually with USA, China, India and Italy being the largest producers respectively. Similarly, India produces 8.7 million MT of eggplants (*Solanium* sp.) on yearly basis (Ghadsingh and Mandge, 2012). Tomato according to these authors is the world's most processed crop with the magnitude of microbes-induced postharvest losses in the fresh fruits estimated at between 25 and 80%. In various fruit trees, Arya (2010) reported that postharvest losses in USA (1 to 20%), India (10 to 40%) occurred while Gupta et al. (2012) reported losses of up to 20-30% to occur in onion (Alliaceae; *Allium cepa*) production due to black mould.

Apart from these huge losses in the quantity of produce, postharvest rot-losses have a lot of other consequences on produce quality (Nwachukwu and Osuji, 2008). Some workers reported that spoilage organisms produce extra-cellular enzymes such as amylases, celluloses, zylanases, polygalactunases and pectin-methyl esterases which degrade cell wall components of susceptible produce leading in some cases to emission of foul odour and water (Salami and Popoola, 2007; Amadioha, 2012; Oladoye et al., 2013). Hence rots reduce the market value of affected produce, hamper the addition of value to them and prevent produce to complete their roles in the food chain. In a bid to keep these organisms at bay, controls are employed which increase the cost of production. These costs are passed over to the end users of the commodities.

Another very important impact of spoilage and postharvest deterioration by fungal pathogens is the production of various types of mycotoxins on produce such as oil seeds, maize and cereals. Mycotoxins are low molecular weight toxic secondary metabolites from some species of fungi. They are dangerous in minute quantities and present extreme toxicity due to their ability to withstand heat (Okigbo, 2004; Shukla et al., 2012). The mycotoxins of most agricultural importance are aflatoxins, fumonisins, ochratoxin A, zearalenone and deoxynivanelol (Bankole and Adebanjo, 2003). According to this source fungal toxin contamination of food products can cause acute or chronic intoxications, leads to reduced life expectancy; exacerbate disease conditions in humans leading to 40% loss of economic productivity. Mycotoxins are carcinogenic, cytotoxic, hepatotoxic, nephrotoxic and teratotoxic. They affect agricultural economies of developing countries, reducing their produce exportability (Shukla et al., 2012). Many conditions warrant and stimulate spoilage, rots and production of mycotoxins on produce by microorganisms. Fresh cassava tubers are very highly perishable under ambient conditions. According to Ubalua and Oti (2008), enzyme-mediated changes begin in the root tubers of cassava within one day following harvest, leading to loss of tuber quality in a space of 3 days. Consequently, the tubers become subject to fungal invasion. In yams, rots are exacerbated by high ambient temperatures and relative humidity of tropical zones (Nahunnaro, 2008). Besides, unhealthy store conditions lead to the absorption of moisture by produce in storage as a result of defects in the storage facility, thus encouraging the development of hot-spots and moulds (Shukla et al., 2012). According to Bankole and Adebanjo (2003), ear borers such as *Mussida* sp., *Sitophilus zeamais* and *Carpophilus dimidiatus* have been linked with aflatoxin contamination of maize cobs right from the field. These insect pests bore into kernels of grains providing portals for easy entrance and colonization of the affected kernels by mycotoxin organisms. Pre-harvest aflatoxin production in maize is exacerbated by wet weather conditions during crop maturation following insect damage. The risk is high when environmental conditions are characterized by soil moisture stress with elevated temperatures which could crack and rupture testa of grains. In pre-harvest rots of tuber crops, nematodes also have been suggested to play important roles in creating portals of entry to rot inciting organisms. Many nematodes have been implicated in this dimension including species of *Meloidogyne, Scutellonema, Helicotylenchus, Rotylenchus* and *Practylenchus* (Okigbo, 2004; Carsky et al., 2010). In the overall, yams infected in the field, rot speedily in storage. Apart from inclement weather and poor storage conditions of our tropical storage systems, another factor that contributes to rots of produce is inappropriate handling. With the exception of *Colletotichum* spp. which can penetrate healthy tissues of fresh produce, rot organisms are mainly low-grade fungi, and as such wound requiring and wound assisted (My Agriculture Information Bank, 2013). Improper handling leaves-off bruises on produce during harvesting, transit or storage. Bruises may become contaminated from adherent soils or air-borne propagules which later colonise such abrasions to cause rots (Okigbo, 2004; Okigbo and Nmeka, 2005). This review hence, highlights the different control strategies for control of fungi induced rots of tubers and agro-produce and emphasized the efficacy of plant-derived pesticides in their control.

Rot inciting organisms

According to Arya (2010) postharvest pathogens can be divided into those that penetrate the produce on-farm, but develop in their tissues only after harvest, during storage or marketing on one hand; and those that initiate penetration and colonization during or after harvest on the other. Enormous postharvest losses have been attributed to fungal deteriorations (Okigbo, 2002, 2003; Shukla et al., 2012). From a study on cassava in Souhteast Nigeria, fungal pathogens reportedly associated with its tuber rot include *Botrydiplodia theobromae, Fusarium solani, F. oxysporium, Aspergillus niger, Rhizopus stolonifer, Diplodia manihotis* and *Cylindrium clandestrium, Macrophomina phaseolina, Penicilium oxalicum*. *A. niger* (dry rot) and *F. oxysporium* (wet rot) were reported as being the most abundant. However, the most virulent of the species were *P. oxalicum* and *A. niger* (Okigbo et al., 2009a; 2009c). A study on yams revealed that *A. niger* was the most frequently occurring species associated with yam tuber rots in the same location (Okigbo and Ikediugwu, 2000). In cocoyam, the greatest storage losses have been attributed to *Penicillium digitatum, Sclerotium rolfsii, Fusarium solani* and *Aspergillus flavus* (Nwachukwu and Osuji, 2008; Anukworji et al., 2012). In some cases, bacteria (*Pseudomonas* and *Erwinia*) may play associative roles in rots of vegetables. According to My Agriculture Information Bank (2013) only 36% of postharvest rots of vegetables are attributed to bacteria. Oladoye et al. (2013) reported from DNA sequencing studies in Southwest Nigeria that *Staphylococcus acuri* and *Rabniell sp*. were associated with spoilage of vegetable sweet potato. *Fusarium redolens* and *F. oxysporium* were implicated in the deterioration of *Solanum tuberosum* (potato). In yams, Nahannaru (2008) noted that up to 30 different fungi have been reported in yam storage rots. He remarked that species of *Rhizopus, Mucor, Circinelloides, Sclerotium* and *Rhizoctonia* caused rapid collapse of cell walls in soft rots. The author reported that *R. stolonifer* was associated with rot of yams in Yola, Northeast Nigeria. Similarly a study in Southeast Nigeria underscored *A. niger* as the most common and virulent pathogen responsible for postharvest deterioration in yams in the zone (Okigbo, 2004). Some of the important postharvest rot organisms of agricultural produce are listed in Table 1.

However, as seen from Table 1, fungi are the most important and prevalent microorganisms responsible for infecting and rotting a wide range of produce including fresh fruits, and causing economically important losses during transit or storage (Ukeh and Chiejina, 2012). In developing countries, as reported Shukla et al. (2012), the greatest losses to durable commodities such as yam tubers and cereals are fungi induced. It has been reported that the mechanism by which parasitic diseases occur involves an interchange of metabolites between the pathogen and the host fruit tissue. Fungi and bacteria of the genera *Erwinia* upon contact with their host tissues secrete cell wall degrading enzymes against them

Table 1. Postharvest rot and spoilage organisms of tubers, fruits and agricultural seeds.

Crop	Microorganisms	Source
	Botrydiplodia theobromae	Nahunnaro (2008)
	Roellinia brunides	“
	Rhizoctonia solani	“
	Sclerotium rolfsii	“
	Mucor spp.	“
	Circinelloides spp.	“
	Rhizopus stolonifer	Taiga (2011)
	Aspergillus niger	Okigbo and Nwakammah (2005)
	Fusarium moniliforme	Nahunnaro (2008)
	Penicillium sclerotigenum	“
	Henderosomdium forulvidae	“
	Macrophomina phaseolina	“
	Rhizopus nodorus	Okigbo and Nmeka (2005)
	Aspergillus flavus	“
Yam (*Discorea* spp.)	*Penicillium chrysogenum*	“
	Geotrichum spp.	“
	Penicillium digitatum	Okigbo et al. (2009b)
	Collectotrichum spp.	“
	Aspergillus tamari	“
	Cladosporium herbarium	“
	C. sphacrosperunum	“
	Cylindrocapon radicicola	“
	Fusarium poa	“
	Penicillium expansum	“
	P. italicum	“
	P. oxalicum	“
	Serratia sp.	“
	Trichoderma spp.	“
	Fusarium solani	Okigbo et al. (2009a)
	F. oxysporium	“
	Candida spp.	“
	Aspergillus niger	“
	Aspergillus tamari	“
	Mucor spp.	“
	A. flavus	“
	Penicillium oxalicum	“
	P. digitatum	“
	Trichoderma viride	“
Cassava *(Manihot sp.)*	*Neurospora* spp.	“
	P. chrysogenum	“
	Botrydiplodia theobromae	“
	Geotrichum candidum	“
	Rhizopus stolonifer	“
	Diplodia manihottis	“
	Cylindrium cladestrium	“
	Trichoderma haziarum	“
	B. acerina	Amadioha and Makson (2007a)
	Rhizopus oryzae	Amadioha and Makson (2007b).

Table 1. Continues.

	Sclerotium rolfsii	Nwachukwu and Osuji (2008)
	Aspergillus niger	Ugwuoke et al. (2008)
	Fusarium solani	“
Cocoyam	*Botrydiplodia theobromae*	“
	Fusarium oxysporium	“
	Corticium rolfsii	“
	Penicillium digitatum	Anukworji et al. (2012)
	Monilocheates infuscans	Amienyo and Ataga (2007)
	Ceratocystis fimbriata	“
	Macrophomina phaseolina	“
	Botrytis cinerea	Banso (2009)
	Erysiphe polygoni	“
Sweet potato (*Ipomea sp.)*	*Diaporthe batatalis*	“
	Moriella ramanniana	“
	F. nivale	“
	R. stolonifer	“
	A. fumigatus	“
	R. stolonifer	“
Irish potato	*Rhizopus oryzae*	Salami and Popoola (2007)
	Fusarium redolens	“
	F. oxysporium	“
	Penicillium sp.	“
	Alternaria solani	“
	Rhizogospora spp.	“
	Heminsthoporium solani	“
	Colletotrichum atramentarium	“
	Aspergillus niger	“
	Pythium ultimum	“
	Phytophtora infestans	“
	P. parasitica	“
	Rastoma solanacearium	Bidarigh et al. (2012)
	Verticillium sp.	“
	Erwinia carotovora	Bdiiya and Dahiru (2006)
Tomato and eggplant *(Solanium sp.)*	*Alternaria, alternata*	Ghadsingh and Mandga (2012)
	Colletotrichum sp.	”
	Fusarium solani	”
	Phoma sp.	”
	Rhizoctonia solani	”
	Phomopsis vexans	”
	Phytophtora sp.	”
	Phytophtora infestans	”
	Rhizopus stolonifer	”
	Aspergillus niger	
	Mucor piriformis	Ukeh and Chiejina (2012)
	P. digitatum	”
	Fusarium oxysporium	”
	Geotrichum candida	Ijato et al. (2011)

Table 1. Continues.

Maize	*Aspergillus flavus*	Bankole and Adebanjo (2003)
	A. parasitica	”
	A. nominus	”
	Fusarium moniliforme	”
Groundnut	*Aspergillus flavus*	Bankole and Adebanjo (2003)
Citrus	*Penicillium citrinum*	Arya (2010)
Grapes	*Botrytis cinerea*	Arya (2010)

(Salami and Popoola, 2007). For instance, *E. carotovora* causes enzymes-mediated soft rot of potato and tomato which poses a serious problem in warm and wet tropics. In cocoyam, rots incitants have also been reported to possess cellulolytic and pectinolytic enzymes capable of degrading cell wall polymers and making available carbon sources in the cocoyam to the invading fungi (Ugwuoke et al., 2008).

CONTROL OF ROTS AND SPOILAGES OF AGRO PRODUCE IN TRANSIT AND STORAGE

In order to meet the food demand challenges of our teeming economies, and to attain sufficiency and security in food production, food production must be matched adequately with their protection from spoilage and rots-inducing organisms during transit or storage (Shukla et al., 2012). In a bid to control these organisms and the deterioration or rots attendant from them, several control techniques have been devised. Some are highlighted below.

Good agronomic practices, field sanitation and store hygiene

According to various workers, rotting usually starts from the field and progresses in storage (Okigbo and Ikediugwu, 2000; Okigbo, 2004). Arya (2010) observed that pre-harvest cultural practices are essential and if well adopted, will considerably reduce postharvest diseases during storage. This source remarked that in fruit orchards for example, collection of rotted fruits, dumping them into deep trenches and covering them with thick layers of soil or burning them away from the orchard will aid in reducing the transmission of the rot pathogens from one fruit to the other. So also the rouging of diseased bunches from the trees. In an evaluation in yams, Okigbo (2004) reported that pre-harvest rots are due to infection of the tubers by soil-borne pathogens. Hence, according to Bankole and Adebanjo (2003) cleaning the field of remains of previous harvest and destroying infested crop residues are basic sanitary measures against rots incitants. There is need also for early planting that disallows crop maturity from coinciding with periods of peak rain regimes. Such early harvesting has been advocated to reduce the risk of mould build-up and mycotoxin contamination in susceptible produce. Pre-harvest insects and nematode controls have also been identified as essential to good storability of agro-produce as the activities of these organisms have been found to have profound effects on rots development and severities in stored products. While nematodes create entry and infection points on produce through root wounding in the soil, insects do same to grains on ears of corns, rice, wheat etc. and good field control of these organisms reduces the risk of rots of produce in storage (Okigbo, 2004; Bankole and Adebanjo, 2003). High moisture contents of produce or grains contribute to deterioration of produce in storage by fungal pathogens (Shukla et al., 2012). Rapid drying of grains and other produce from the farm has been emphasized as an important step to avoiding rots of produce. Bankole and Adebanjo (2003) reported that dry grains keep longer, safe from insects and moulds because the water activity required for their growth is not met. Drying harvested maize for instance to 18.5% moisture content within 48 h after harvesting reduces the risk of mould growth on them. Besides, the factors of insect infestation and high moisture contents in stored products encourage mycotoxins build up on such products. Maize, groundnut and yam chips are mycotoxins-prone. Some species of fungi have been associated with mycotoxin production in grains. These are *Aspergillus, Penicillium, Fusarium, Alternata* and *Cladosporium*. Mycotoxins are toxic to humans and animals. The toxicity of mycotoxins such as aflatoxins and fumonisins stems from their extreme stability to high temperatures; and dangerous nature in minute quantities (Shukla et al., 2012). Presence of deposits of mycotoxins in grains in turn reduces the market value of such agro-products (Bankole and Adebanjo, 2003). The authors reported that disposing heavily damage maize ears from the farm (those with greater than 10% ear damage) reduce aflatoxin deposit levels in maize. In high rainfall areas such as Southern Nigeria, in addition to sun drying, grains especially maize and melon seeds are spread on the floor and turned occasionally till the produce are dried. They may be stacked on raised platforms under cover to shield them from rains or in some cases dried over fire places. Another important factor is store condition and hygiene (Shukla et al., 2012). This source remarked that defects in the storage facility lead to moisture absorption by stored products, creating mouldiness and hot-spots. Therefore efforts should be made to prevent moisture migration into grains through leaking roofs and condensation resulting from inadequate store ventilation (Bankole and Adebanjo, 2003). Cleaning of stores properly before loading in the new harvest will not only reduce rots but correlated according to Hell et al. (2000) to reduced aflatoxin deposits in the grains.

Thermal and physical control

Curing involves exposing harvested tubers to high temperatures and relative humidity (RH) for a short time usually about 24 h. In the curing process of cassava for example (Okigbo et al., 2009a) reported that the fresh harvested tubers are exposed to temperature range of 25 to 35°C and 80 to 90% RH for 7 to 14 days. According to Okigbo (2004), curing naturally encourages thickening of the tuber skin. It allows healing of wounds and abrasions sustained during harvesting through surberin formation at wound sites, and subsequent development of periderm or corky layer over the wounds. Consequently, the corky layer callouses-off infective agents and prevents water loss from the wounds. Hot water dips and hot vapour exposures are another means of control. Salami and Popoola (2007) reported the association of *B. orzyae, Furisarium redolens*, *F. oxysporium* and *Penicillium* spp with rot of Irish potato in Ibadan and Jos, Nigeria. According to Agrois (1998), parasitic diseases commonly arise as a result of environment-moderated interchange of metabolites between an invading parasite and the host tissue of plants. Enzymes are known to be the first weapons of attacks selected by pathogens upon contact with compatible host plant tissues. Many plant pathogenic organisms are capable of producing cell wall degrading enzymes such as amylases and celluloses. Salami and Popoola (2007) found that blanching the tubers in hot water (60°C) significantly controlled rots induced by these fungi and enhanced their storable period. It could be that this thermal treatment, denatured these cell wall degrading enzymes produced by these pathogens, thereby affecting their arrest and control. According to Arya (2010) postharvest decay of strawberries (*Botrytis cinerea*) was controlled also by exposure of the fruits to hot humid air at 40°C for about 1 h. Low temperatures have been employed in the treatment and control of rots in fruits, vegetable etc. This has been inferred as causing inactivity of the organism without being able to kill them. The danger with low temperature storage lies in the fact that as soon as favourable conditions prevail, the organisms begin the rot process in the fruits since they were only hibernating. Low temperature storage require hi-tech facilities and constant power supply which may be within reach of resource-rich farmers of Europe and America and not so for their counterparts in Nigeria whose production and storage capabilities are strongly challenged by erratic electric power supply. Despite these short-comings however Okigbo (2004) found that storing yam tubers at 16 to 17°C improved their storage life for up to four months. He however, remarked that lower temperature of <10°C is more effective in preserving the tubers against rot organisms; but the attendant chilling damage associated with such temperature is one of the most important deterrents to its industrial applications.

Biological control of rot organisms

Biological control of plant diseases involves the practice whereby the growth, survival and activity of a pathogen is reduced via the agency of any other living organism and with the result that there is reduction in the evidence of the disease caused by the pathogen. According to Okigbo (2004), soil-derived non-pathogenic strains of *Bacillus subtilis* and *Trichoderma viride* are potent bio-control agents which controlled postharvest and storage rots of yam tubers. A single application of this bio-control agent protected tubers in storage for up to 6 months (Okigbo and Ikediugwu, 2000). In parallel studies, the saprophytic strain of the bacterium *Pseudomonas syringe* (L – 59 – 66) also satisfactorily controlled the difficult grape rots (*B. cinerea*) and blue mould of *Citrus* (*P. citrinum*) (Arya, 2010). This saprophyte has been developed into a commercial brand (Ecosuinex). *B. subtilis* showed similar strong fungitoxic activity and has been adopted to control anthracnose of avocado caused by *Colletotrichum gloesporoides*. In some instances, research has shown that combining bio-control agents with some derivatives or out-right chemicals increased their activity. According to Arya (2010), nitrogenous and starch compounds (L-aspartigine and D-glucose) used in association with the bio-agent *Candida saitiana* decreased postharvest rot diseases of fruits while the growth and development of rot organisms on pear was reduced 95% by synergizing a strain of *Penicillium expansum* with thiobendazole. In addition to being eco-friendly, the need for repeated spray applications as in synthetic fungicides is unnecessary with biological control agents (Okigbo, 2004). Although the mechanisms of action of these bio-control agents have not been fully explained, competition for space and nutrients, antibiosis, direct parasitism, as well as rapid and effective colonization of wound sites against the invading pathogens has been presumed and suggested for their activity (Okigbo, 2004; Arya, 2010; Suprapta, 2012).

Chemical control of rots and their causal agents in postharvest produce

Synthetic pesticides have long-standing reputation in agriculture. Their use has been credited with enhancing yield of agricultural crops and increasing the returns on investment on farm capital (Bennett, 2005). They are fast-acting biocides producing instant effects on the pathogens; resulting in the arrest of the disease development and spread (Biobank, 2009; Vikhe et al., 2010). Synthetic pesticides have broad spectrum of application in the field, transit or store. For example Okigbo et al. (2009a) remarked that curing and treating cassava tubers with thiobendazole-based chemical compounds have been noted to delay the onset of deterioration of cassava tubers. Similar report has been given also on cocoyam corms and cormels with the same fungicide (Nwachukwu and Osuji, 2008). Control of rots in yam tubers have been attempted with significant benefits with bleach (sodium hypochlorite), borax, captan and orthiophenylphenate, naphthalene acetic acid, maleic hydrazidine, lime and gin (Okigbo, 2004; Okigbo and Nmeka, 2005). For example, the protectant fungicide captan was found to completely inhibit the germination of spores of the rot-inducing organisms *Fusarium moniliforme, Botrydiplodia theobromae* and *Penicillium sclerotigenum* while benlate and thiobendazole arrested both spore germination as well as growth of these pathogenic species. However, these chemicals are heavy-duty chemicals whose demerits are abundant in science literature (Enyiukwu and Awurum, 2013a). Arya (2010) reported that quick disappearing chemical compounds such as ozone, sulphur dioxide (SO_2) and acetic acid in recent times have been evaluated as fumigants for use in postharvest protection of produce especially fruits; to reduce dependence on conventional chemical compounds. These low-weight chemicals have proved effective in eradicating most rot-inducing organisms in grapes. In addition, gamma and ultraviolent radiations are being explored against postharvest rots causing pathogens. This source noted that UV light has germicidal effects and reduced the activity of PAL and peroxidase enzymes in rot inciting organisms. These advantages notwithstanding, fungicide formulations effective enough to control such postharvest diseases as rot of grapes (*B. cinerea*) and blue mould of *Citrus* (*P. citrinum*) are as yet not found (Arya, 2010). A similar report was issued with regard to some field fungal diseases. Pythium soft rot (*P. alphanidermatum*), *Fusarium* and *Verticillum* wilt diseases were emphasized as difficult to control diseases. They were reported to be not adequately controlled with synthetic pesticides interventions (Knowledge Scotland, 2010). Synthetic chemicals use in plant protection are being de-emphasized for their toxic residues in crops; which causes death through chronic and acute toxic exposures in mammals (Tripathi and Dubey, 2004; Taiga, 2011). They accumulate in the ecosystem with long degradation periods or may degrade to more toxic forms (Enyiukwu, 2002). This broad spectrum of activity spills into eradicating non-target species such as pollinating bees and butterflies in the ecosystem (Shukla et al., 2012; Enyiukwu and Awurum, 2013a). Apart from these, Okigbo (2004) reported their use restrictions in some countries. In addition, they have been implicated in stimulating development of resistance in 150 pathogenic fungal species. For instance, strains of *Colletotrichum* spp. (anthracnose) are now known to be resistant to some of the most effective fungicides such as benomyl, carbendazim and thiophenate-methyl (Pinstrup-Anderson and Panda-lorch, 1994; Enyiukwu and Awurum, 2013a). The development of resistance to known agricultural pesticides by fungal pathogens in recent years has become a very serious problem in crop production and protection (Tripathi and Dubey, 2004). This phenomenon of resistance has been reported to occur within 7 to 10 years post-introduction of every given agricultural chemical formulated to control pathogenic fungal organisms (Oreskes and Conway, 2010). These and many more such as finding new techniques of managing postharvest diseases recalcitrant to synthetic fungicide such as bunch rot of grapes (*B. cinearea*) and blue mould of *Citrus* (*B. citrinum*) gave impetus to search for alternatives (Arya, 2010). One such viable alternative is the use of plant-derived pesticides (Enyinkwu and Awurum, 2011, 2012, 2013b). The exploitation of natural products such as plant extracts and essential oils as alternative strategy in controlling postharvest fungal rots of tubers, fruits and vegetables have been advocated (Tripathi and Dubey, 2004; Amadioha and Markson, 2007a, b; Shukla, 2012). These plant-based pesticides are reported as cheap, easily available in tropical farming localities of Nigeria, easy to prepare, biodegradable by light components and microbes, systemic and less likely for pathogens to develop resistance against them (Opara and Wokocha, 2008; Opara and Obana, 2010, Adjaye-Gbenwonyo et al., 2010; Enyiukwu and Awurum, 2013a). Okigbo (2005) suggested that it is important to adopt control practices that are affordable, durable, consistent or integrable with prevailing agricultural practices specific to the farming population of an area. Use of plant-derived pesticides in tropical farming systems of Nigeria met these requirements.

Use of plant-derived pesticides in the control of postharvest rot diseases

Shukla et al. (2012) reported that numerous *in vitro* studies have validated the efficacy of plant-derived pesticides in many branches of agriculture. Comparatively however, fewer *in vivo* works have been done on stored products caused by moulds and storage bacteria. These investigators however inferred that plant materials were fungitoxic and prophylactic against rots organisms. According to Okigbo et al. (2009a) many rot inducing organisms of cassava including *A. niger* were inhibited *in vitro* by plant-based fungicides from *A.*

meleguata and *A. indica*. Okigbo et al. (2009c) reported that *Allium sativum* exhibited the toxic effects on all the organisms assayed in a study while *O. gratissimum* retarded the mycelial growth of the mycoflora by 64%. In another study, Amadioha and Markson (2007a) found extracts of *Piper nigrum*, *Ageratum conyzoides* and *A. melegueta* to significantly arrest the mycelial growth and biomass development of *Botrydiplodia acerina* causal agent of rot of cassava *in vivo.* According to Taiga (2011) 40% aqueous extract of *Nicotinia tabacum* completely inhibited yam rot development (*Rhizopus stolonifer*) *in vivo*. In like manner, ash of plantain peels, aided in prolonging the shelf-life of bruised yam tubers (Nahunnaro, 2008). A related study demonstrated that extracts and powder formulations of *Cassia alata* and *Dennettia tripetala* effectively checked the growth, development and spread of *Sclerotium rolfsii* induced rot of corms of cocoyams (Nwachukwu and Osuji, 2008). Phytopesticides from *Afromomium meleguata* and *Zingiber officinale* reportedly inhibited *Penicillium digitatum, Mucor piriformis*, *Aspergillus niger* and *Heminsthoporium solani* causal agents involved with soft rot of tomato (Chiejina and Ukeh, 2012; Ukeh and Chiejina, 2012). Similarly, *Rhizopus stolonifer* and *Fusarium oxysporium* amongst other pathogens were also reported inhibited by extracts from *Chromolaena odorantum, Azachirachta indica, Vernonia amygdalina* and *Tridax procumbens* in eggplants and tomato (Ijato et al., 2011). Not only have the mycelial growth of the pathogenic species been reported retarded by the several extract formulations, they have also been noted to inhibit myco-pathogenic spores germination. For example, investigators have reported the inhibition of the germination of the conidia of the fungus *Fusarium oxysporium* (Rongai et al., 2012). Those of *Colletotrichum destructivum* as well have been observed to be inhibited and reported (Enyiukwu and Awurum, 2011). Extracts used to control different rots and rots inciting organism are presented in Table 2.

From Table 2, it could be observed that plant-derived pesticides from different species of higher plants demonstrated fungitoxic activity against several fungi that attack agro-produce in transit and store. Thirty (30) different pathogens in yam alone were reported inhibited by phyto-pesticides. It follows therefore that these extracts are exploitable sources of novel chemotherapeutants to fight the ravages of plant pathogenic fungal species in order to sustain and increase agricultural production to meet the yearning demands of the populace. However, the efficacy of the plant extracts were affected by a number of factors as highlighted below:

Formulation

The way and form in which the extract is presented against the pathogenic disease affects its efficiency. In recent studies in Southeast Nigeria on cowpea, it was obtained that coating the seeds of cowpea with powder films of the assayed plant materials were superior in inhibition effects and improving the germination potentials of the stored cowpea seeds; compared to seed-dressing them by immersion in aqueous extracts of similar spice plants (Awurum and Uchegwu, 2013; Awurum and Enyinkwu, 2013). In a related study also, Owodade and Osikanlu (1999) reported that the fungitoxic activity of slurry preparations of *Acalypha ciliate* and *Ocinum gratissimum* proved superior also as seed-dressing preparations compared to aqueous application.

Combination of extracts

The effects may be unity, suppressive or synergistic. In a study also in Southeast Nigeria, Ubulua and Oti (2008) reported that ethanol extracts of *A. sativum* and *Landolphia owerrence* exhibited broad-spectrum activity against fungal pathogens associated with cassava rot. The combination of the extracts *A. sativum* and *Garcimia kola* was found to demonstrate remarkable inhibition of the assayed pathogens after 16 days in storage with only 2% rot; while that of *A. sativum and L. owerrence* roots exhibited little or no activity. Montes-Belmount and Prados-Ligero (2006) reported from studies in Cameroun, that the combination of extracts showed that the effect of each plant could be modified by the reactions of the complex mixture of plant compounds in the extracts. For instance in studies on Onion rot (*Sclerotium rolfsii*) a mixture of extracts of *Piper nigrum* and clove (*Syzygium aromanticum*) resulted in enhanced and synergistic inhibition effect against the causal pathogen while all combinations involving clove and other extracts resulted in single fungicidal (unity) effect. However, they noted that all combinations of other extracts with allspice (*Pimerta dioica*) showed antagonistic influences and negative inhibition effects. Bhardwaj (2012) in like manner, reported from a study conducted in India that that seed extracts of *Dedonia viscosa* also showed strong inhibition of *Fusarium solani* and combination of leaf extracts of *Acacia catechi* and *Lawsonia alba* resulted in efficient enhancement of their antifungal activities over the individual extracts of each plant material against the mycelial growth of the pathogenic organism in potato.

Extractants

The efficiency of activity of an extracts correlated to the type of active ingredient(s), it contains and the relative amount of the principles(s) in the extracts (Owolade and Osinkanlu, 1999). The amount of an active ingredient in an extract is a principle function of solubility of the active ingredient (a.i) which in turn is influenced by the type of

Table 2. Effects of phyto-pesticides in the control of rots and storage diseases of agro-produce.

Diseases	Crop	Pathogen	Extract	Source
Tuber rot	Cassava	*Botrydoplodia acerina* *Rhizopus oryzae* *Aspergillus niger* *B. theobromae* *Fusarium solani* *Penicillium oxalicum*	*Piper nigum* seed *A. meleguata* seed *A. conyzoides* leaf *A. indica* leaf *A. meleguata* seed	Amadioha and Markson (2007a; 2007b) Okigbo et al. (2009a) " "
Corm rot	Cocoyam	*A. niger* *F. solani* *B. theobromae* *F. oxysporium* *Sclerotium rolfsii* *S. rolfsii* *F. solani* *S. rolfsii* *B. theobromae* *A. niger*	*Carica papaya* *Vernomia amygdalina* *Ocimum basilicum* *A. indica* *Dennettia tripetala* *Cassia alata* *Garcinia kola* *A. indica* *Allium cepa*	Ugwuoke et al. (2008) " " " Nwachukwu and Osuji (2008) Anukworji et al. (2012) " "
Tuber rot	Sweet potato	*R. stolonifer* *F. nivale* *A. fumigatus* *R. stolonifer* *B. theobromae* *F. solani* *F. oxysporium*	*A. indica seed* *Moringa oleifera seed* *Z. officinale* *Monodora myristica* *Annona muricata* *A. sativum* *Alchornea cordifolia* *Garcinia kola* *Z. officinale*	Tijjani et al. (2013) " Banso (2009) " Amienyo and Ataga (2007) " " ‘‘
Tuber rot	Irish potato	*Rastoma solanacearium* *Rhizoctonia batatas* *Erwinia* *Carotovora* spp. *Carotovora.** *Fusarium solani*	*Ocimum basilicum* *Nerium oleancler* *Azadirachta indica* *Ocimum gratissimum* *Cymbopogon citratus* *Azadirachta indica* *Lawsonia alba* *Acacia catechi* *Dedonia viscosa*	Bidarigh et al. (2012) Amadioha (2004) Bdiiya and Dahiru (2006) Bhardwaj (2012) "
Tuber rot	Yam	*F. oxysporium* *A. niger* *B. theobromae* *A. niger* *A. flavus* *F. oxysporum* *R. stolonifer*	*Chromolaena odoranta* *A. indica* *Xylopia aethiopica* *Zingiber officinale* *Musa* sp. peel (ash) *V. amygdalina* leaf *A. indica* seed oil *Elais guineensis* leaf	Okigbo et al. (2010) " Okigbo and Nmeka (2005) " Nahunnaro (2008) " "
Tuber rot	Cassava	*B. theobromae* *R. stolonifer* *Mucor sp.* *Aspergillus flavus* *Fusarium solani*	*Z. officinale* *Landophia owerrience* *Garcinia kola* *A. sativum*	Ubulua and Oti (2008) " " "

Table 2. Continues.

Tuber rot	Yam	*F. oxysporium* *A. niger* *R. stolonifer* *P. oxalicum*	*Nicotinia tabacum* *A. indica* *A. barbadensis*	Taiga (2011) ” ”
Seed rot	Egusi melon	*R. stolonifer* *Penicillin italicum* *A. niger*	*Ocimum gratissimum* *A. indica*	Chuku et al. (2010) ” ”
Fruit rot	Tomato	*Mucor piriformis* *Aspergilus niger* *Heminsthoporium solani* *Penicillium digitatum* *Geotrichum candida* *F. oxysporium* *R. stolonifer* *A. niger*	*A. meleguata* seed *Z. officinale* *Tridex procumbens* *V. amygdalina* *C. odorantum* *A. indica*	Ukeh and Chiejina (2012) ” Ijato et al. (2011)
Fruit rot	Citrus	*Z. officinae* *C. frutescence*	*P. digitatum* *A. niger*	Singh et al. (2012)
Tuber rot	Yam	*A. niger* *A. flavus* *B. theobromae* *F. oxysporium* *F. solani* *P. chroysopenum* *P. oxalicum* *R. stolonifer* *Pseudomonas* spp. *Klebsiella* spp.	*Ficus thomongii* *F. exasperate* *F. sur* *F. suassureana*	Oyelana et al. (2011) ” ” ” “ “ “ “ “
Seed rot	Cowpea	*A. niger* *P. digitatum* *Botrytis cinerea* *Rhizopiro arrhizus* *A. flavus* *Choatomium brasilliense* *Rhizoctonia solani*	*Annona reticulata* *Agemone mexicana* *Ipomea carnea* *Partherium hysterophorus* *Tridex procumbens* *Cathranthus roseus* *Eucalyptus globules*	Mogle (2013) ” ” ” ” ” ”
Rot	Maize/tomato	*Alternaria solani* *Fusarium moniliforme*	*Hermidesmus indicus* *Withania sominifera* *Rauwolfia tetraphylla.*	Sangrikar and Wadje (2012)
Tuber rot	Hausa Potato	*Fusarium oxysporium,* *Aspergillus niger,* *Penicillium expansum,* *Rhizopus stolonifer*	*Angeissus leiocarpus ash,* *Sorghum bicolour*	Mohammed et al. (2013)
Seed Rot	Rice	*Bipolaris oryzae*	*Callistemon citrinus* *Ocimum gratissimum*	Nguefack et al. (2007)

Table 2. Continues.

Seed rot	Soybean	*Mucor mucedo* *P. chrysogenum* *Cephalosporium sp.* *A. flavus* *A. niger* *A. fumigatus* *R. stolonifer* *F. oxysporium* *R. leguminocola* *Alternaria alternata* *Colletotrichum dermatum* *Macrophomina phaseolina* *Sclerotium rolfsii* *Phoma sp.* *Curvularia lunata*	*A. indica* *Acacia nilotica* *Datura stramonium* *Polyathia longifolia* *A. sativum* *Annona squamosa*	Rathod and Pawer (2012) ” ” ” ” ” ” ” ” ” ” ” ” ”
Kernel rot	Maize	*A. niger* *A. flavus* *Rhizopus spp.* *Curvularia spp* *Mucor spp* *Cladospermatum sp.* *F. oxysporium* *Alternaria alternata* *Phoma* spp. *Herminsthoporium* spp.	*A. indica* *Datura metel* *Parthenium hysterophorius* *Vitex negunde*	Vikhe et al. (2010) “ “ “ “ “
Root rot	Cowpea	*Pythium alphanidermatum*	*Aloe vera leaf,* *Garcinia kola seed,* *Azadirachta indica,* *Zzingiber officinal*	Suleiman and Emua (2009)
White rot	Onion	*Sclerotium ceporium*	*Syzygium aromantica* *Piper nigrum* *Pimentia spp.* *Cinnamonium sp.* *Pachyrhizus erosus*	Montes-Belmont and Prados-Lageri (2006)
Black mould	Onion	*Aspergillus niger*	*Datura stramonium* *Ocimum sanctum* *A. indica* *Eucalyptus spp.*	Gupta et al. (2012)
Kernel rot	Sorghum/ vegetables	*Spacelotheca sorghi* *F. oxysporium* *Aspergillus sp.* *C. gramminicola*	*Lantana camara* *Ocimum sp.* *Hyptis sp.* *Cymbopogon sp.*	Zida et al. (2008); Syed et al. (2012)
Kernel rot	Sorghum	*Phonia sorghince* *F. moliniforme* *C. gramminicola*	*Cympopogon citratus* *E. camaldulensis* *A. indica*	Somda and Sereme (2007)

Table 2. Continues.

Kernel rot	Maize	*A. niger* *A. flavus* *Fusarium* sp. *P. oxalicum* *C. lunata* *R. stolonifer*	*A. sativum* *A. indica*	Debnath et al. (2012)
Fruit rot	Pawpaw	*A. niger* *B. theobromae* *F. solani* *Penicillium* sp.	*Acalypha ciliata* *C. odoranta* *Carica papaya*	Ilondu (2011)
Seed rot	Cowpea/ Maize/ Melon/ Groundnut	*A. flavus* *A. niger* *P. expansum* *R. stolonifer*	*A. ciliata* *A. vera* *A. indica* *V. amygdalina*	Onyeani et al. (2012)
Rot	Fruits /vegetables	*Alternaria* spp.	*Lonicera japonica* *Bacharis trimera* *Cynara scolymus* *Salvia sclarea* *S. officinalis* *Rosmarinus* spp. *Schimus molle* *Aloe vera* *Lippie alba*	Dellavalle et al. (2012) “ “ “ “ “ “ “
Seed Rot	Rice	*Mucor chetomium* *B. oryzae* *F. oxysporum* *F. solani* *A. flavus* *A. alternata* *R. solani* *Pythium ultimum* *Rhizopus* sp.	*M. crystallinum* *Blackiella aellen* *Arthrocnemon glancum* *Atriplex halimus* *Thymilaena hirsute* *Cardinus getulus*	Abd-Ellatif et al. (2011) “ “ “ “ “ “
Rot	Cashew-nut	*Aspergillus spp.,* *Trichodrema spp.,* *Cephalosporium sp.*	*Anacardium occidentalis leaf* *Vernonia amygdalina leaf.*	Suleiman and Ogundana (2010)
Rot	Musk bean, Cucumber	*Phytophtora drechsleri* *Verticillium diahlae* *Scleretina scleroiorium* *Aternaria sp.* *Botrytis cinerea* *Macrophomina phaseolus*	*Perganum hamala* *(shoot, flower, seed)*	Sarpeleh et al. (2009)

solvent used in the extraction. This is one major factor besides particle size of the plant material which underpins the reason for variation of activity in assayed extracts (Gurjar et al., 2012; Enyiukwu et al., 2013). In a study in Uruguay, it was observed that a high proportion of the test plant extracts in water (80% of them) did not inhibit the fungus *Alternaria* sp. However, all extracts from buffer and acid solvents demonstrated a wide range of inhibitions (11 to 99.9%) against the pathogen. The study concluded that it was only *Cynara scolymus* whose extracts from water, buffer and acid solvents showed appreciable inhibitions (78 to 98%) suggesting that the active ingredients has different affinity to the extractants (Dellavella et al., 2012). In like manner from a study in India, Gujar and Talwankar (2012) showed that extractants have profound effects on activity of extracts. They remarked that inhibition of *Ocimum sanitum*, *O. basilcum* and *Lantana camara* against the storage pathogens *A. flavus, A. niger, R. solani* and *R. bataticola* was solvent-dependent being highest in alcohol, followed by acetone and least in water.

Green plants provide a reservoir of effective chemicals that can be exploited against phyto-parasites. Table 2 confirms that numerous plant species possess fungitoxic secondary metabolites. Regrettably only 12000 to 15000 phyto-metabolites have been identified out of the estimated 4,000,000 thought to constitute the chemical space in higher plants (Pallant, 2010; Shukla et al., 2012). Plant extracts contain a wide range of bioactive secondary metabolites which include alkaloids, flavonoids, tannins, saponins, phenols, phlobatannins quinones, lecitins, polyphenols, glycosides, terpenoids, polypeptides and steroids (Edeoga et al., 2005; Shukla et al., 2012; Enyiukwu and Awurum, 2013a). These bioactive groups of natural products have been given as the reason for their inhibitive roles against pathogens in ethnobotany, drug application and plant health management (Okwu and Njoku, 2009; Enyiukwu et al., 2013). Aside of crude extracts, many volatile and essential oils from aromatic and forest species have been used successfully in the control of rot organisms. These flavor compounds have high volatility and low water solubility. Volatile aromatic compounds include aldehydes, benzaldehydes, hexane and hexanal while essential oils are characterized and dominated by monoterpenes and sesquiterpenes. Vapours of acetylaldehyde have been used to control *B. cinerea* and *R. stolonifer* induced spoilage in strawberry while essential oils from *Cymbopogon martini, Thymus zygis, Eugenia aromanticus* and *Cinnamonum zeylanicum* significantly controlled rots (*B. cinerea*) in several fruits reported Arya (2010). Cinnamon oil, according to Jham et al. (2005) which effectively killed *Aspergillus flavus* and *A. niger* contain 61% cinnamaldehyde and 29% cinnnamic acid. The most frequently occurring constituents of most essential oils have been reported to be limonene, α-pinene, β-pinene, β -myrcene and camphor. It is reported that vapour of thyme reduced the development *B. cinerea* in mandarin fruits by damaging the fungal hyphae (Arya, 2010). A study in Cameroon showed that essential oils from *Cymbopogon citratus, Ocimun gratissimum* and *Thymus vulgaxis* were able to reduce the *Fusarium verticiloides* load on maize seeds by 90 to 100% (Tagne et al., 2006). A wide ranging effect of essential oils from plants of many genera and families against storage fungi have be reviewed and presented by Shukla et al. (2012).

Though phyto-derived pesticides possess proven fungitoxic activities as seen from Table 2; however, little have been reported on their modes of action on the target pathogens. And where they exist they are suggestions or postulations. Reports say the mechanisms of action of phyto-metabolites against pathogens are not thoroughly understood yet (Shukla et al., 2012: Enyiukwu et al., 2013). For instance (STK, 2013) reported that extract of *Melaleuca alternifolia* acts against fungus-induced black sigatoka disease of banana by altering the permeability of the membrane structures of the pathogenic organism. This leads ultimately to loss of cellular integrity and loss of cytoplasm. It also inhibits respiration and blocks ion transport of the affected cells. There are approximately 100 secondary metabolites in extracts of *M. alternifolia* (Noumi et al., 2011) and scientists thought α-terpene-4-ol is the principal active ingredient. Others are cineole, γ-terpinene and α-pinene (Kulkarni et al., 2008; Melaleuca, 2013). There is dint of multi-bioactive principles effects in these reported modes of action of *M. alternifolia* (Enyiukwu and Awurum, 2013a; Enyiukwu et al., 2013). The question now is which constituent is responsible for these modes of action advanced by STK (2013)? *Azadirachtin,* a sesquiterpene from *A. indica* according to reports have strong antioxidant activity. The many aflatoxin-inhibition activities of its extracts are thought connected with this antioxidant activity (Holmes et al., 2008). The compound cinnaldehyde obtained from the plant *Cinnamonium zeylanicum* is suggested to act against susceptible pyhtopathogenic fungi by interfering with their glucose uptake and utilization. The investigator remarked that this mechanism of action is not fully understood yet (Brown, 2006). More work is pressingly needed at this stage in these areas of cytotoxicity and natural products chemistry to give assertive reports on the active ingredients of plant origin and how they affect the reported inhibitions of pathogens.

CONCLUSION

It is important to adopt disease control practices that will be affordable by the bulk of resource-poor farmers in our part of the world. Such plant protection strategy must be durable, compatible and integrable with the prevailing agricultural practices specific to our people. It is noteworthy therefore, that use of plant-derived pesticides in crop production meets these criteria and hence warrants their exploitation in crop production. Compared to synthetic chemicals extracts of plant origin offer the benefits of pre- and post-infection fungitoxicity and leave no toxic load on produce. This therefore makes them an input of choice particularly in organic farming and in low-input conventional farming systems. Plant-derived pesticides require no pre-harvest interval (PHI) before treated produce can be harvested and consumed. They are eco-compliant; being less likely to harm farm-friendly bees, butterflies and earthworms. Extracts of plant origin are biodegradable and hence are efficient tools in reducing or eliminating pesticides persistence problems in the environment. Because they offer wide ranging modes of action against pathogens, plant extracts aids in delaying resistance problems in agriculture and as such usable in both conventional and organic farming systems. Application of plant-derived pesticides not only in field interventions, but especially in storage will spell improvement in sustainable food production and food security programmes of developing countries of the world with nearly 1 billion severely hungry people. Use of plant extracts to fight rots and spoilage diseases decimating stored agricultural products in sub-saharan African countries like Nigeria, undoubtedly reflects the least–cost method of arresting phyto-fungal diseases in the country.

RECOMMENDATIONS

1. More works need to be done in the area of the phytochemistry of extracts. Plant extracts are complex mixtures of compounds. The facts of one potentiating, inhibiting or competing with others cannot be ruled out. We need to fractionate the extracts to identify, isolate, purify and then characterize the principle(s) responsible for these reported controls.
2. This will also aid in our bids to better formulate the extract to deliver the active principles in the best possible ways against the pathogen without them undergoing any chemical changes that could hamper their activity.
3. More researches are needed to determine standard extractants for extracting the active principles from the plants either based on family or genera of plants or based on the type of compound(s) being sought.
4. Biotechnology and genetic engineering technologies should be strongly emphasized and adopted in the study of these fungitoxic phyto-metabolites to explore and exploit possibilities of encoding rapidly growing weeds or some saprophytes with the genetic ability to produce these metabolites rather than depending solely on combinatorial chemistry for chemical development.

REFERENCES

Abd-Ellatif S, Abdel Rahman SM, Deraz SH, 2011. Promising antifungal effect of some forkloric medicinal plants collected from El-Hamman habitat Egypt against dangerous pathogenic and toxigenic fungi. APRN J Agric Biol Sci, 6(9):25-32.

Adjaye-Gbewonyo D, Quaye EC, Wubah DA, 2010. The effects of extracts of *Piper guineense* seed on insect pest damage to cowpea. J Young Investigators, 20(1):264-256.

Agrois GN, 1998. Plant Pathology (Edition 3). Academic Press INC., New York. 703pp.

Amadioha AC, 2004. Control of black rot of potato caused by *Rhizoctonia bataticola* using some plant leaf extracts. Arch Plant Pathol Plant Prot, 37:111-117.

Amadioha AC, 2012. Reducing food losses through sustainable methods of plant disease management: an imperative for actualization of food security in Nigeria. A paper presented at the 13th inaugural lecture MOUAU, June, 2012.

Amadioha AC, Markson AA, 2007a. Postharvest control of cassava tuber rot caused by *Botrydiplodia acerina* using extracts of plant origin. Arch Phytopathol, 40(5):359-366.

Amadioha AC, Markson AA, 2007b. Control of storage rot of cassava tuber caused by *Rhizopus oryzae* using some plant extracts. Arch Phytopathol, 40(6):381-388.

Amienyo CA, Ataga AE, 2007. Use of indigenous plant extracts for the protection of mechanically injured sweet potato (*Ipomea batatas* (L.) Lam) tubers. Sci Res Essay, 2(5):167-170.

Anukworji CA, Putheti RR, Okibgo RN, 2012. Isolation of fungi causing rot of cocoyam (*Colocasia esculenta* (L.) Schott) and control with plant extracts: (*Allium sativum* L., *Garcinia kola, Azadiachta indica* and *Carica papaya* L.). Global Adv Res J Agric Sci, 1(2):33-47.

Arya A, 2010. Recent advances in the management of plant pathogens: Botanicals in the fungal pest management. In: Management of fungal plant pathogens. Arya A. and Perello, A. E. (Eds). UK, CAB International, pp. 1-25.

Awurum AN, Enyiukwu DN, 2013. Evaluation of the seed-dressing potentials of phytochemicals from *Carica papaya* and *Piper guineense* on the germination of cowpea (*Vigna unguiculata* L. Walp) seeds and incidence of the seed-borne fungi. Cont J Agric Sci, 7(1):29-35.

Awurum AN, Uchegwu PO, 2013. Effects of duration of contact of seed extract of *Piper guineense, Monodora myristica and Xylopia aethiopica* on the germination and incidence of seed-borne fungi of stored cowpea *(Vigna unguiculata* L. Walp) seeds. Cont J Biol Sci, 6(1):37-42.

Bankole SA, Adebanjo A, 2003. Mycotoxins in food in West Africa: Current situation and possibilities of controlling it. Afr J Biotechnol, 2(9):254-263.

Banso A, 2009. Effects of extracts of *Monodora myristica* and *Zingiber officinale* on the growth of fungi in sweet potato. Afr J Microbiol Res, 3(9):487-490.

Bdiiya BS, Dahiru B, 2006. Efficacy of some plant extracts in the control of potato tuber soft rot caused by *Erwiniacarotovora* ssp *caotovora*. J Plant Prot Res, 46(3):285-294.

Bennett D, 2005. Farm Press – New study shows the benefits of fungicides use. www.westernfarmpress.com/new=study-shows. Retrieved Oct. 12, 2012.

Bhardwaj SK, 2012. Evaluation of plant extracs as antifungal agents against *Fusarium solani* (Mart.) Sacc. World J Agric Sci, 8(6):385-388.

Bidarigh S, Massiha A, Mohamme RM, Khoshkoholgh P, Issazadeh K, Muradov PZ, Azapour E, 2012. Antimicrobial (screening) properties of various plant extracts from *Ocimum basilicum* L. and *Nerium oleander* L. against common fungal organism of potato. J Basic Appl Res, 2(7):6810-6815.

Biobank, 2009. Farming methods comparison. www.omz.jp/?page_id=271 Retrieved May 9. 2010.

Brown AE, 2006. Mode of action of insecticides and other related pest control chemicals for production agriculture, ornamentals and turf. Pesticide education and assessment program. Retrieved May 30, 2012. http://pesticide.umd.edu

Carsky R, Asiedu R, Cornet D, 2010. Review of soil fertility management for yam-based systems in west Africa. Afr J Root Tuber Crop, 8(2):1-17.

Chiejina NV, Ukeh JA, 2012. Antimicrobial properties and phytochemical analysis of methanol extracts of *Afromonium meleguata* and *Zingiber officinale* on fungal disease of tomato fruit. J Nat Sci Res, 2(6):10-17.

Chuku EC, Osakwe JA, Eke J, 2010. Fungi flora of melon seeds (*Citrullus colocynthis*) and their response seed treatment. *Scientia Africana* 9(2):77-82.

Debnath A, Sultana A, Rashid AQM, 2012. Effect of seed-borne fungi on the germinating seeds and their biocontrol in maize. J Environ Sci Nat Res, 5(1):117-120.

Dellavelle PD, Cabrebra A, Allem D, Larranaga P, Ferreira F, Rizza D, 2010. Antifungal activity of medicinal plant extracts against phytopathogenic fungus *Alternaria* spp. Chilean J Agric Res, 71(2):231-239.

Edeoga HO, Okwu DE, Mbaebie BO, 2005. Phytochemical constituents of some Nigerian medicinal plants. Afr J Biotechnol, 4(7):685-688.

Enyiukwu DN, Awurum AN, 2011. Effects of phytochemicals from *Carica papaya* roots and seeds and *Piper guineense* seeds on the germination of spores of *Colletotrichum destructivum.* Cont J Biol Sci, 4(20):55-59.

Enyiukwu DN, Awurum AN, 2012. Comparative fungitoxicity of benomyl and extracts of *Carica papaya* roots and seeds and *Piper guineense* seeds on *Colletotrichum destrucivum* O'Gara. Cont J Biol Sci, 6(1):38-42.

Enyiukwu DN, Awurum AN, 2013a. Fungitoxic principles and antifungal activity of extracts from *Carica papaya* and *Piper guineense* on *Colletotrichum destructivum*. Cont J Biol Sci, 7(1):29-36.

Enyiukwu DN, Awurum AN, 2013b. Fungitoxic effects of *Carica papaya* and *Piper guineense* extracts against *Colletotrichum destructivum* in the glasshouse. Cont J Agric Sci, 7(1):23-28.

Enyiukwu DN, Awurum AN, Ononju CC, Nwaneri JA, 2013. Use of plant extracts in plant disease management: role and significance of characterization of secondary metabolites from higher plants in phyto-disease management. Int J Adv Agric Res. In Press

Ewell PT, Matuura J, 1991. Tropical root crops in a developing economy. Proceeding of the 9th symposium of the International Society for Tropical Root Crops 20-26 October 1991 Accra Ghana. Pp. 405.

Ghadsingh PG, Mandge SV, 2012. Nutritional spoilage of tomato and brinjal fruits due to postharvest fungi. Curr Bot, 3(4):10-12.

Gujar J, Talwankar D, 2012. Antifungal potential of crude plant extracts on some pathogenic fungi. World J Sci Tech, 2(6):58-62.

Gupta R, Khokhar MK, Lai R, 2012. mManagement of black mould of onion. J Plant Pathol Microbiol, 3(5):3-5.

Gurjar MS, Ali S, Akhtar M, Singh KM, 2012. Efficacy of plant extracts in plant disease management. Agric Sci, 3(3):425-433.

Hell K, Cardwell KF, Setamou M, Poehling HM, 2000. The influences of storage practices on aflatoxin contamination of maize in four agroecological zones of Benin, West Africa. J Stored Prod Res, 36:365-382.

Holmes RA, Boston RS, Payne GA, 2008. Diverse inhibitors of aflatoxin biosynthesis. Appl Microbiol Biotechnol, 78(4):559-572.

Ijato JY, Adebiyi AO, Ijadnola JA, 2011. Antifungal effects of four tropical plants aqueous and ethanolic extracts on postharvest rot tomato (*Lycopersicon esculenta*) in Ado-Ekiti, Nigeria. New York Sci J, 4(1):64-68.

Ikotun T, 1986. Microbial rots of tubers of Chinese yam (*Dioscorea esculentus*) in storage. Fitopatologica Brasiliera, 11:241-244.

Ilondu EM, 2011. Evaluation of some aqueous plant extracts used in the control of pawpaw fruit (*Carica papaya* L.) rot fungi. J Appl Biosci, 37:2419-2424.

Jham GN, Dhinngra OD, Jardim CM, Valente VMM, 2005. Identification of the major fungitoxic components of Cinnamon bark oil. Fitopatologia, 30:404-408

Kana HA, Aliyu IA, Chammang HB, 2012. Review on neglected and underutilized root and tuber crops as food security in achieving the millennium development goals in Nigeria. J Agric Vet Sci, 4:27-33.

Kleih U, Phillips D, Ogbonna M, Siwoku B, 2012. Nigeria-Scoping Yam Value Chain Analysis. Yam Improvement for Income and Food Security in West Africa. pp 1-53.

Knowledge Scotland, 2010. Plant pathogens resistant to fungicides. Retrieved may 9, 2010 http:// www.knowledscotland.org/breifings.php.

Kulkarni A, Nasreen J, Seema N, 2008. Monitoring of antimicrobial effect of GC_MS standardized *Melalueca alternifolia* (Tree Tea oil) in multidrug resistant uropathogens. IOSR J Pharm Biol Sci, 2(2):6-12.

Melaleuca, 2013. Discovering *Melaleuca* oil's natural effectiveness. pp 120-122.

Mogle UP, 2013. Efficacy of leaf extracts against the postharvest fungal pathogens of cowpea. Biosci Discovery, 4(1):39-42.

Mohammed A, Chimbekujwo IB, Bristone B, 2013. Identification and control of fungi associated with the post-harvest rot of *Solenostemon rotundifolius* (Poir) J. K. Morton in Adamawa State. J Agric Healthcare, 3(5):136-140.

Montes-Belmont R, Prados-Ligero AM, 2006. Influence of plant extracts on *Sclerotium cepivorium* development. Plant Pathol J, 5(3):373-377.

My Agriculture Information Bank, 2013. Microbial losses in fruits and vegetables. In: Nature and causes of deterioration in fruits and vegetables. www.agriinfo.in/defalt.aaspx?page=topic&spuperid=2&topicid=1429 Retrieved October 28, 2013.

Nahunnaro H, 2008. Effects of different plant extracts in the control of yam rot induced by *Rhizopus stolonifer* on stored yam (*Dioscorea* spp.) in Yola, Adamawa State, Nigeria. Medwell J Agric Sci, 3(5):382-387.

Noumi E, Snoussi M, Hajlauui H, Trabeisi N, Ksouri R, Valentin E, Bakhrouf A, 2011. Chemical composition, antioxidant and antifungal potential of *Melaleuca alternifolia* and *Eucalyptus globulus* essential oils against oral *Candida* species. J Med Plant Res, 5(17):4147-4156.

Nguefack J, Torp J, Leth V, Lekane-Dongmo JB, Fotio D, Amvan-Zollo PH, 2007. Effects of plant extracts and chemical fungicides in controlling rice see-borne fungus under laboratory and irrigated cropping system in Ndop-Cameroon. Afr Crop Sci Proc, 8:791-796.

Nwachukwu EO, Osuji JO, 2008. Evaluation of plant extracts for antifungal activity against *Sclerotium rolfsii* causing cocoyam cormel rot in storage. Res J Agric Biol Sci, 4(6):787-793.

Nwokocha HN, 1992. Agronomy of sweet potato. Root Crop Research and Technology Transfer Training Course (Manual) NRCRI, pp77-84.

Okigbo RN, Agbata CA, Echezona AC, 2010. Effect of leaf extracts of *Azadirachta indica* and *Chromolaena odorantum* on post-harvest spoilage fungi of yam in storage. Curr Res J Biol Sci, 2(1):9-12.

Okigbo RN, Okorie RE, Putheti R, 2009c. *In vitro* effects of garlic (*Allium sativum*) and African basil (*Ocimum gratissimum*) of pathogens isolated from rotted cassava root. INCI Interciencia 34(10):742-748.

Okigbo RN, Putheti R, Achusi CT, 2009a. Post-harvest deterioration of cassava and its control using extracts of *Azadirachta indica* and *Afromonium meleguata.* E-J Chem, 6(4):1274-1280.

Okigbo RN, 2002. Mycoflora of tuber surface of white yam (*Dioscorea rotundata*) and postharvest control of the pathogens with *Bacillus subtilis.* Mycopathologica, 156:81-85.

Okigbo RN, 2004. A review of biological control methods for postharvest yams (*Dioscorea spp.)* in storage in South Eastern Nigeria. KMITL Sci Technol J, 4(1):207-215.

Okigbo RN, 2005. Biological control of postharvest fungal rot of yams (*Dioscorea spp.)* with *Bacillus subtilis.* Mycopathologica, 159:307-314.

Okigbo RN, Anuagasi CL, Amadi JE, 2009b. Advances in selected medicinal and aromatic plants indigenous to Africa. J Med Plant Res, 3(2):86-95.

Okigbo RN, Ikediugwu FEO, 2000. Studies in the biological control of postharvest rot of yams (*Dioscorea rotundata*) with *Trichoderma viride.* J Phytopathol, 148:331-335.

Okigbo RN, Nmeka IA, 2005. Control of yam tuber rot with leaf extracts of *Xylopia aethiopica and zingiber officinale.* Afr J Biotechnol, 4(8):804-807.

Okigbo RN, Nwakammah PT, 2005. Biodegration of white yam (*Dioscorea rotundata)* and water yam (*Dioscorea alata*) slices dried under different conditions. KMITL Sci Technol J, 5(3):1-10.

Okigbo, R. N. (2003). Fungi associated with peels of postharvest yams in storage. Global J Pure Appl Sci, 9(1):19-23.

Okwu DE, Njoku EE, 2009. Chemical composition and *In vitro* antifungal activity screening of seed and leaf extracts from *Afromonum melenguata* and *Monodora myristica* against *Sclerotium rolfsii* of cowpea plant. Pest Tech, 3(1):58-67.

Oladoye CO, Olaoye OA, Cornnerton IF, 2013. Isolation and identification of bacteria associated with spoilage of sweet potatoes during postharvest storage. Int J Agric Food Sci, 3(1):10-15.

Onyeani CA, Osunlaja SO, Oworu OO, Joda AO, 2012. Evaluation of effect of aqueous plant extract in the control of storage fungi. Int J Sci Tech Res, 1(6):76-79

Onyeka J, Chuwang PM, Fagbola O, 2011. Baseline studies on the status of yam research for development: status of yam research in Nigeria. Pp 1-52. www.iita.org/c/document_library/et_file/p_l_id.

Opara EU, Obana FT, 2010. Performance of some plant extracts and pesticides in the control of bacterial spot disease of *Solanium.* Medwell Agric J, 5(2):45-49.

Opara EU, Wokocha RC, 2008. Efficacy of some plant extracts on the *in vitro* and *invivo* control of *Xanthomonas campestris pv vesicatoria.* Medwell Agric J, 3(3):163-170.

Oreskes N, Conway EM, 2010. Denial rides again; the revisionist attack on Rachel Carson. In: Merchants of doubt. NY, Bloomsbury. pp. 216-235.

Owolade BF, Osinkanlu YOK, 1999. Evaluation of some plant extracts for the control of brown blotch disease of cowpea in Southwest Nigeria. J Sust Agric Environ, 1(2):198-202.

Oyelana OA, Durogbo EU, Olukaanni OD, Ayodele EA, Aikulola ZO, Adewole AI, 2011. Antimicrobial activity of ficus leaf extracts on some fungal and bacterial pathogens of *Diascorea rotundata* L. from Southwest Nigeria. J Biol Sci, 11(5):359-366.

Pallant AC, 2010. Bioactivity of alkaloidal fraction of Tabernaemontana elegans Stapf. Thesis (*MagisterScientiae*) submitted to the Deparment of Pharmacology, Faculty of Health Sciences, University of Pretoria, 2010.

Pinstrup-Anderson P, Panda-lorch R, 1994. Alleviating poverty, intensifying agriculture and effectively managing natural resources. A Food, Agriculture and Environment discussion paper Washington DC 20:13-14.

Rathod LR, Pawar PV, 2012. Antimicrobial activity of medicinal plant to control seed-borne pathogen of soybean. Curr Bot, 3(2):10-12.

Rongai D, Milano F, Scio E, 2012. Inhibitory effect of plant extracts on conidial germination of the phytopathogenic fungus *Fusarium oxysporium*. Am J Plant Sci, 3:1693-1698.

Sadiku NA, Sadiku IBS, 2011. Indigenous efforts by African farmers in ensuring sustainability in agricultural productivity in the face changing climate: A proceeding of the *Environmental Management Conference*, FUNAAB, Nigeria, 2011.

Salami OA, Popoola OO, 2007. Thermal control of some postharvest rot pathogens of Irish potato (*Solanum tuberosum* L.). J Agric Sci, 52(1):17-31.

Sangrikar VR, Wadje SS, 2012. *In vivo* testing of plant extracts against seed-borne pathogens. Int Res J Biol Sci, 1(6):1-4.

Sarpeleh A, Sharifi K, Somboikar A, 2009. Evidence of antifungal activity of wild rue (*Peganum harmala* L.) on phytopathogenic fungi. J Plant Dis Prot, 116(5): 208-213.

Shukla AM, Yadav RS, Shashi SK, Dikshit A, 2012. Use of plant metabolites as an effective source for the management of postharvest fungal pest: A review. Int J Curr Discoveries Innovations, 1(1): 33-45.

Singh H, Al-Samarai G, Syarmabil M, 2012. Exploitation of natural products as an alternative strategy to control postharvest fungal rotting of citrus. Int'l J Sci Res Publ, 2(3): 1-4.

Somda I, Leth V, Sereme P, 2007. Evaluation of lemongrass, eucalyptus and neem for controlling seed-borne fungi of sorghum grown in Burkina Faso. World J Agric Sci, 3(2):218-223.

STK, 2013. Timorex-Gold (*Melaluecaalternifolia*) The new generation of Bio-fungicides, full control of black sigatoga. Stockhon Group, pp 1-6. www.stockhon-ag.com Retrieved June 10, 2013.

Suleiman MN, Emua SA, 2009. Efficacy of four plant extracts in the control of root rot disease of cowpea. Afr J Biotechnol, 8(16):3806-3808.

Suleiman MN, Ogundana AF, 2010. Evaluation of two plant leaf extracts on fungi associated with biodegradation of cashew nuts in storage. Ann Biol Res, 1(4):41-44.

Suprapta DN, 2012. Potentials of microbial antagonist as biocontrol agents against plant fungal pathogens. J ISSAAS *18*(2):1-8.

Tagne A, Feujio TP, Sonna C, 2006. Essential oils and plant extracts as potential substitutes to synthetic fungicides in the control of fungi. Endure International Conference, Diversifying Crop Protection, France, October 12-15, 2008, pp 1-3.

Taiga A, 2011. Comparative studies of the efficacy of some selected Fungicidal aqueous plant extracts on Yam tuber dry rot disease. Ann Biol Res, 2(2): 332-336.

Taiga A, 2009. Efficacy of selected plant extracts in the control of fungal dry rot of white yam (*Dioscorea rotundata*) tubers in Kogi State. American-Eurasian J Sust Agric, 3:310-313.

Talwana HAL, Serem AK, Ndabikunze BK, Nandi JOMR, Tumuhimbise R, Kaweesi T, Chumo EC, Palapala V, 2009. Production status and prospects of cocoyam (*Olocasia esculentus* (L.) Schott.) in East Africa. J Root Crops, 35(1):96-107.

Tijjani A, Adebitan SA, Gurama AU, Aliyu M, Dawakiji AY, Haruna SG, Mohammed NA, 2013. Efficacy of some botanicals for control of wet rot disease of mechanically injured sweet potato caused by *Rhizopus stolonifer* in Bauchi State. Int J Sci Res Pub, 3(6):1-10.

Tripathi P, Dubey AK, 2004. Exploitation of natural plant products as an alternative strategy for control of postharvest fungal rotting of fruits and vegetables. Postharvest Biol Tech, 32(3):235-245.

Ubalua AO, Oti E, 2008. Evaluation of the antimicrobial properties of some medicinal plants for fresh cassava root tuber preservation. Pak J Nutr, 7(5):679-681.

Ugwuoke KI, Onyeke CC, Tsopmbeng NGR, 2008. The efficacy of botanical protectants in the storage of cocoyam (*Colocasia esculenta* (L.) Shott). Agro-Sci J Trop Agric Food Environ Ext, 7(2):93-98.

Ukeh JA, Chiejina NV, 2012. Preliminary investigations of the cause of postharvest fungal rot of tomato. IOSR J Pharm Biol Sci, 4(3):36-39.

Vikhe AM, Wabala HS, Wabala AS, Reddy PG, 2010. Efficacy of plant extracts against the seed-borne fungi of zea mays L. Asian J Exp Biol Sci SPL, 109-111.

Zida PE, Sereme P, Leth V, Sankara P, Somda I, Neya I, 2008. Importance of seed-borne fungi of sorghum and pearl millet in Burkina Faso and their control using plant extracts. Pakistan J Biol Sci, 11: 321-331.