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Potentials of Tropical African Spices as Sources of Reduced-Risk Pesticides

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ABSTRACT

Increased demand for more sustainable agricultural practices and organic products coupled with renewed awareness of potential negative effects of conventional pesticides on the environment are serving as impetus to resort to reduced-risk plant-based pesticides. Most indigenous tropical African spices like *Aframomum melegueta*, *Aframomum citratum*, *Piper guineense* and *Xylopia aethiopica* are often advantageously widely used as low-cost, eco-friendly, low-risk pesticidal alternatives to the conventional synthetic pesticides. These usually hot tasting, highly aromatic and strongly pungent culinary spices are often associated with ethnomedical uses. Several empirically validated studies have confirmed that these very odorous, locally available folkloric plants in Africa are potent insect feeding deterrents, repellents and often possess fumigant and/or insecticidal activities as well as have potent antimicrobial activities against major pathogens. Since some constituents of essential oils from aromatic plants hinder the octopaminergic nervous system unique to insects, these culinary spices are hence potential sources of reduced-risk pesticides. Given the prospects of global warming, when it is postulated that most pestiferous organisms will experience shortened developmental cycles and hence altered seasonality and increased number of generations per any given time, demand for easily available and biodegradable, low-cost and low-risk pesticides for low-income peasant farmers and organic farmers in general will likely increase. This study therefore gives a synoptic overview of the uses of the aforementioned spices as antifeedants, repellents and insecticides as well as antimicrobials. Prospects and challenges for vulgarizing these potential alternative plant protectants in the face of anticipated climate change and hence large-scale ecological and agricultural changes are also highlighted.

Key words: African spices, antifeedants, repellents, insecticides, antimicrobials

INTRODUCTION

Despite the known negative effects of synthetic chemical pesticides to humans, other beneficial organisms and the environment in general, if injudiciously used, these conventional pesticides are still a vital tool in crop protection when crop damage become great enough to warrant emergency measures. To circumvent or minimise the high cost and potential hazards of these chemicals, farmers need to resort to more creative, easily affordable and sustainable pest management methods to combat pest problems so as to sustain or increase yields and ensure food security. Given the array of selective pressures that pests exert on plants, it is obvious that the plant kingdom offers a tremendous diversity of bioactive phytochemicals that can serve as complementary or alternatives to the conventional synthetic chemical pesticides. With the exception of sulphur, botanical insecticides have been used longer than any other type of insecticide (Pedigo and Rice, 2006). Plant extracts or their potent derivatives such as derris, rotenone, pyrethrum, nicotine, sabadilla,

physostigmine, quassin or azadirachtin, have been used as insecticides for decades (Sarfraz and Keddie, 2005; Simmonds *et al.*, 1992). Botanical pesticides are of interest to organic farmers because the chemicals are natural products, hence easily biodegradable and are often thought of being safe to handle and use on food products. Some botanicals or their derivatives such as pyrethrum-based products have made an impact in crop protection and this has rekindled hopes for the resurgence of plant-derived pesticides. Plant-derived pesticides are traditionally used and produced by farmers in developing countries where these botanicals are locally readily available and appear to be quite safe and promising (Stoll, 2000). Complex mixtures of lethal and sub-lethal phytochemicals in botanicals often offer multi-factorial selective pressures that retard the development of resistance in pests (Ntonifor *et al.*, 2006). It is postulated that with global warming, pests will have shortened developmental periods and hence increased number of cycles per given time with a consequent exacerbation of pest problems.

Given such a scenario, easily available, low-cost, eco-friendly and reduced-risk botanicals may become attractive alternative pesticides to resource-poor farmers in developing nations and organic farmers in general. Extracts and plant-derived chemicals of fruits, leaves and even roots of some tropical African spicy plants have been variously used as protectants of post-harvest and field pests for decades. In spite that some of these claims have not been scientifically empirically validated, there is abundant documented evidence that some of these extracts and/or their derivatives are potent antifeedants, repellents, fumigants or contact poisons of some major insect pests. Others have antimicrobial activities against some major plant pathogenic organisms. This study offers a synoptic overview of the biological activities of the following highly fragrant commonly used tropical African spices; *Aframomum melegueta* (Rosk) K. Schum (Zingiberaceae), *Aframomum citratum* (Pareira) K. Schum (Zingiberaceae), *Piper guineense* Schum et Thonn (Piperaceae) and *Xylopiya aethiopica* (Dual) A. Rich (Annonaceae). Some challenges that require addressing as pre-conditions to the large-scale sustainable exploitation of these valuable environmentally friendly alternative pesticides in the face of global warming and hence altered pest scenarios are also highlighted.

Antifeedant, repellent and insecticidal activities of plant derivatives

Grains of paradise, *Aframomum melegueta*: *Aframomum melegueta* is a tufted, leafy, herbaceous perennial with short, scaly rhizome and a surface root system; it is cultivated and occurs throughout the tropics though native to tropical Africa (Iwu, 1993; Dokosi, 1998). The plant, especially the spicy edible fruit is used as a spice and flavouring in food but also medicinally as well to control plant pests and diseases.

Laboratory dual- and no-choice antifeedant activities of fruit extracts of the Grains of Paradise, *A. melegueta* (Alligator pepper) have been elucidated using larvae of the Egyptian cotton leaf worm *Spodoptera littoralis* (Boisduval) (Lepidoptera: Noctuidae). Leaf portions treated with either hexane or methanolic fruit extracts showed strong dose-dependant antifeedant activities (Ntonifor *et al.*, 2006). Similarly, the hexane, methanol and most importantly water extracts of *A. melegueta* deterred feeding in third instars of one of the worldwide most important pests of cruciferous crops, the diamond back moth *Plutella xylostella* L. (Lepidoptera: Yponomeutidae) in laboratory bioassays. Furthermore, the methanol and water extracts of the plant also caused at least 80% mortality of second instars of the pest (Ntonifor *et al.*, 2010). The pesticidal potentials of *A. melegueta* as a feeding deterrent were also demonstrated earlier by Escoubas *et al.* (1995). These authors showed that derivatives of the plant possess strong antifeedant actions against termites attributed to the presence of the arylalkanoids 6-shogaol and gingerol. This may be an indirect

validation of the folkloric indigenous methods of dispersing columns of drivers ants *Dorylus* sp. by chewing the fruits of *A. melegueta* and spewing out the chewed pungent fruits across the column of the ants which dispels the insects. Consistent with the potentials of *A. melegueta* as a reduced-risk pesticide for field insect pests, aqueous extracts from the plant have also been used to significantly reduce the abundance of *Maruca vitrata* Fab. (Lepidoptera: Pyralidae) and *Clavigralla tomentosicollis* Stal (Hemiptera: Coreidae) on field cowpea (Oparaeke *et al.*, 2005). Paradol was identified as the major insecticidal constituent of *A. melegueta* against the cowpea storage bruchid, *Callosobrochus maculatus* (Lale, 2002). *A. melegueta* volatile oils also strongly repelled *S. zeamais* adults from maize grains thus highlighting the potential of using them in the protection of stored grains by resource-poor farmers with local access to these plants (Ukeh *et al.*, 2010).

Each of the methanol and water extracts of the equally highly fragrant closely taxonomically related but relatively less widely studied spice species *Aframomum citratum* also exhibited strong dose-dependent antifeedant activity against *S. littoralis* possibly due to the high content of geraniol in its essential oils (Ntonifor *et al.*, 2006). Geraniol was demonstrated to be a strong repellent against mosquitoes (Xue *et al.*, 2003). Similarly, the hexane and methanol seed extracts of *A. citratum* deterred feeding in *Plutella xylostella* reputed for its ability to develop resistance to most conventional insecticides (Ntonifor *et al.*, 2010). It is hypothesized that pesticidal plant-extracts may be more effective against *P. xylostella* since they may retard the development of resistance than synthetic pesticides or purified derivatives due to synergistic or potentiating interactions among fairly complex phytochemicals in the extracts (Ntonifor *et al.*, 2010). Interestingly and consistent with seed powders of *A. melegueta*, *A. citratum* seed powders also caused significant mortalities of the cowpea seed weevil *C. maculatus* (Coleoptera: Bruchidae). This is indicative that powders from the seeds of *A. citratum* have contact and/or fumigant toxic effects on *C. maculatus* (Oben, 2006).

West African black pepper *Piper guineense*: *Piper guineense* is a climbing perennial forest liana plant with gnarled branchelets spiralling on shrubs to about 10 m. The leaves are elliptic in shape and highly aromatic when crushed. It is used as a flavouring and spice in food but it also has several medicinal (Iwu, 1993) and pesticidal uses. The use of derivatives of *P. guineense* to protect stored grain legumes and cereals against several post-harvest pests is a widespread age long practice in Africa (Olaiya *et al.*, 1987). Crude extracts, essential oils and seed powders of the plant are effective against the cowpea bruchid, *Callosobruchus maculatus* (Ivbijaro and Agbaje, 1986; Ofuya and Dawodu, 2001) and also the closely related species *C. subinnotatus* on bambarra groundnut (*Voandzeia subterranea*) seeds (Oparaeke and Bunmi, 2006). *P. guineense* seed powder exhibited acute toxicity and also significantly reduced oviposition and emergence of *C. subinnotatus* adults. Seed essential oils of the plant are also efficacious against *Tribolium castaneum* on stored millet seeds (Lale and Yusuf, 2001). Several studies devoted to the evaluation of *P. guineense* seed powders and its other derivatives on many weevils have been carried out. Products of the plant are effective against the boll weevil, *Anthonomus grandis* Boh. (Scott and McKibben, 1978) and the rice weevil, *S. oryzae* (Su, 1977). *P. guineense* seed products have equally demonstrated their repellent, insecticidal and ovicidal potencies (Ntonifor and Monah, 2001; Tchoumboungang *et al.*, 2009) as well as behaviour modifying capacities of the maize weevil, *S. zeamais* (Awasalam and Emosairue, 2006; Awasalam *et al.*, 2007). *Sitophilus zeamais* adults were significantly repelled by odours from *P. guineense* (Ukeh *et al.*, 2010). An important aspect of these post-harvest studies is

that proximate and chemical analysis of maize seeds treated with oil extracts and powders of black pepper revealed no adverse effects on the nutritional composition, normal colour, taste and texture of the treated grains (Awasalam, 2006).

The potentials of *P. guineense* products as effective insecticides have also been demonstrated on a wide range of major noxious field insect pests of arable crops. Essential oils of the plant exhibited acute toxicity to larvae of *Acrae eponina* Cramer, the adult cotton stainer *Dysdercus superstitionus* Fab., flea beetle *Oothea mutabilis* Sahlberg, and the pod sucking bug *Riptortus dentipes* Fab on cowpea (Olaiya *et al.*, 1987). Ekese (2000) equally showed that crude water extracts of black pepper seeds significantly reduced egg viability of the legume pod borer *Maruca vitrata*. Similarly, crude extracts, essential oils and powders derived from *P. guineense* seeds are effective against the European corn borer *Ostrinia nubilalis* Hubn. (Ewete *et al.*, 1996); thrips, larvae of *Maruca vitrata*, nymphs and adults of the pod sucking bug complex on cowpea dominated by *Clavigralla tomentosicollis* Stal. (Oparaeke, 2007). A laboratory assessment of the repellent and anti-feedant properties of aqueous extracts of *P. guineense* against the banana weevil *Cosmopolites sordidus* Germar revealed potent repellent and feeding deterrent activities of the extracts (Inyang and Emosairue, 2005). Other parts of the African black pepper also have pesticidal constituents; for example a petroleum ether extract of its roots also exhibited insecticidal activity against the house fly *Musca domestica* L. (Gbewonyo and Candy, 1992). This underscores the importance of also screening the more abundant but often grossly underutilized leaves for their biological activities.

The aforementioned studies are eloquent indications that constituents of various parts of the African black pepper are insecticidal and/or have potent anti-insect activities. Some identified bioactive chemicals in *P. guineense* are piperine and chavicine reported to be insecticidal to various crop pests (Su, 1977; Okonkwo and Okoye, 1996). The mode of action of these phytochemicals was reported to be contact toxicity (Olaiya *et al.*, 1987). Ogunwolu *et al.* (1998) also attributed the toxic effects of the powder derivatives of the plant to the presence of piperine type of amine alkaloids. They further postulated that the powder of the West African black pepper may also cause physical abrasion to the cuticle of bruchids with a resultant loss of body fluids or blockage of spiracles. The piperamides found in the genus *Piper* are unique due to their bi-functional nature with the amide functionality being neurotoxic and the methylenedioxyphenyl moiety being an inhibitor of cytochrome P450 enzymes (Scott *et al.*, 2003). A mixture of amides contained in most *Piper* species including *P. guineense* indicates that these plants employ an analogue synergism defence strategy (Berenbaum and Zangerl, 1996) whereby several similar compounds augment the toxicity to herbivores to render it difficult for the insects to adapt and become resistant (Feng and Isman, 1995). Several insecticidal unsaturated isobutylamides including guineensine, pipericide and piperine were identified in *P. nigrum* (Miyakado *et al.*, 1989) and also in *P. guineense* (Parmar *et al.*, 1997). Tchoumboungang *et al.*, (2009) attributed the contact toxicity of *P. guineense* seeds essential oils against *S. zmais* to the presence of a high content of monoterpenes. This spice generally has a high content of terpenoids (Parmar *et al.*, 1997; Ntonifor *et al.*, 2002).

West African pepper, *Xylopi aethiopica*: *Xylopi aethiopica* is an evergreen tall slim tree of about 60-70 cm and 15-30 m in diameter and height, respectively. It is highly aromatic and has straight stems with slightly stripped or smooth back. It is native to the lowland rainforest and moist fringe forest of the savannah zones of Africa (Irvine, 1961; Iwu, 1993). Seeds of *X. aethiopica* are

used as culinary spices, flavourings and to prepare traditional medicines in various parts of Africa; they are also employed as pesticides. Seed essential oils have shown significant dose dependent toxicities to *S. zeamais* adults, repellent activities as well as a reduction of progeny production (Awasalam *et al.*, 2006). In related studies, ethanolic seed extracts of *X. aethiopica* significantly reduced adult fecundity and increased adult mortality of *S. zeamais* on partially resistant stored maize (Babarinde *et al.*, 2008). However, studies using the bruchid *Callosobruchus subinnotatus* on stored bambarra groundnuts seeds treated with *X. aethiopica* seed powder revealed that bruchid mortality was <35% compared to >85% for *P. guineense* treated seeds. The powder instead encouraged more oviposition on the treated seeds compared to seeds protected with *P. guineense* seed powders or even the untreated control (Oparaeke and Bunmi, 2006). Similarly, results of field studies on controlling *Maruca vitrata* and *Clavigralla tomentosicollis* on cowpea also showed that plots treated with *X. aethiopica* aqueous seed extracts had lower grain yields compared to plots treated with similar extract of *P. guineense* or *A. melegueta* singly (Oparaeke *et al.*, 2005). These confirm that *X. aethiopica* is less effective both as a post-harvest and a field pesticide than either of *A. melegueta* or *P. guineense*.

The potent insecticidal activity of essential oils derived from *X. aethiopica* has been attributed to their high terpenoid contents which consist of a mixture of monoterpenes and sesquiterpenes (Awasalam *et al.*, 2006). One of the various effects of plant terpenoids is their toxicity to insects (Metcalf and Metcalf, 1992). Kouninki *et al.* (2007) tested the toxicity of the four main compounds from the seed essential oil against *S. zeamais* namely; α -pinene, β -pinene, Δ -3-carene and terpinen-4-ol and realized that β -pinene and terpinen-4-ol were responsible for 50% of weevil mortality.

Antifungal and antimicrobial activities of derivatives of the target spices: Prospects of *A. melegueta*, *A. citratum*, *P. guineense* and *X. aethiopica* as low-risk antimicrobials against bacteria and fungi have also been demonstrated in a number of studies. Apart from the wide medicinal uses of *A. melegueta* as an antiinfective agent due to its antimicrobial and antifungal activities (Iwu, 1993), it also has enormous potentials as a source of botanical fungicide in particular and antimicrobial in general. Water and ethanol leaf extracts of the plant separately were active against the soft rot causing fungi *Aspergillus niger* and *Fusarium oxysporum* and also significantly reduced the growth of *Botryodiplodia theobromae* mycelium on yam tubers (Okigbo and Ogbonna, 2006). Each of the water and ethanol peppery seed extracts of the plant was used to reduce post-harvest deterioration of cassava caused by *A. niger*, *Fusarium solani* and *B. theobromae* (Okigbo *et al.*, 2009). Aqueous and ethanol extracts of *A. melegueta* similarly prevented growth of the fungi *B. theobromae*, *A. niger*, *A. flavus*, *Mucor* sp., *Rhizopus stolonifer*, *Penicillium* sp. and *Fusarium* sp. isolated from deteriorating okro (Ejechi *et al.*, 2008). Similarly, *A. melegueta* seed powders were effective in reducing the microbial contents of tomato ketchup and minced meat under laboratory conditions (Adegoke and Sagua, 2006). The Antimicrobial activities of *A. melegueta* have been attributed to its essential oils, gingerol, shagaol and paradol amongst other constituents (Iwu, 1993).

Bioassays conducted using the fungi *A. flavus*, *A. niger* and an unidentified yeast strain revealed that aqueous seed extracts of *P. guineense* prevented the growth of the fungi (Ilondu and Iloh, 2007). In a like manner, *A. niger* and *Rhizopus stolonifer* were sensitive to *P. guineense* extracts though the latter was only inhibited at concentrations above 0.5% compared to *A. niger* at lower doses (Eruteya and Odunfa, 2009). The fungi *Fusarium solani*, *Collettrichium* sp., *Pythium* sp. and *Cladosporium herbarium* were sensitive to the essential oils rich hexane and ethyl

acetate extracts of *P. guineense* seeds. Similarly, extracts of *P. guineense* seeds inhibited the growth of *Trichophyton rubrum* and *T. mentagrophytes* and *Basidiobolus haptosporus* (Nwosu and Okafor, 2009).

Studies within the last decade have confirmed that *P. guineense* derivatives are also potent against both gram-negative and gram-positive bacteria strains. For example, essential oils of the spice inhibited the growth of *Pseudomonas aeruginosa* UCH 655 strain which was insensitive to standard antibiotic drugs (Oyedemi *et al.*, 2005). Ground seed powders of *P. guineense* at different doses were also potent against *Bacillus cereus*, *B. megaterium*, *B. coagulans* and *Enterobacter* sp. (Eruteya and Odunfa, 2009). Consistent with the potent antimicrobial action of derivatives of the plant, its ground seed powders reduced spoilage of laboratory-processed tomato ketchup and minced meat (Adegoke and Sagua, 2006). Some indigenous people in parts of West Africa claim that a meal spiced with *P. guineense* takes longer to grow stale compared to its aliquot without the spice.

Gingerol and piperidine were highlighted as the constituents of *P. guineense* responsible for its antifungal action (Deans and Ritchie, 1987) while other authors attributed the activity to the presence of phenolic compounds and essential oils (Benjilali *et al.*, 1984; Farag *et al.*, 1989; Ilondu *et al.*, 2001).

Although *Xylopiya aethiopica* has a wide variety of applications in traditional medicine in Africa, its prospects as an antimicrobial pesticide has also been demonstrated in a few studies. Potent leaf aqueous extracts of the plant were used to reduce the growth of the rot causing fungi *Fusarium oxysporum*, *A. niger* and *A. flavus* on yam tubers (Okigbo and Nmeke, 2005). Ground seed powders of the plant also reduced the bacterial population in tomato ketchup as well as had inhibitory effects on yeast in minced meat (Adegoke and Sagua, 2006).

Hot water extracts from dry fruits of the spice reduced radial growth of the fungi *Ustilago maydis*, *Ustilaginoidea virens*, *Curvularia lunata* and *Rhizopus* sp., thus demonstrating the fungitoxic effects of the extracts (Awuah, 2008). Fruit extracts of the plants are known to be potent against both gram positive and negative bacteria (Iwu, 1993), while xylopic acid from the spice was active against *Candida albicans* (Boakye-Yiadom *et al.*, 1977). Studies of other *Xylopiya* species revealed that their oils exhibited moderate bacteriostatic and fungistatic activities (Fournier *et al.*, 2006).

Perspectives and challenges of using these spices as pesticides: Given the array of documented evidence on the potencies of products of these plants against various pests and microorganisms, it is obvious that these strongly aromatic culinary spices offer a tremendous diversity of bioactive compounds against several plant pests and pathogens. Some of these potent phytochemicals can be used as sources of novel compounds or products on their own rights if given appropriate research attention. Considering that these plants are used as spices, medicinal and aromatic herbs, exploiting them as pesticides will require increased production of the plants. This calls for the development of suitable propagation and cultivation methods. Currently, with the slight exception of *A. melegueta*, most of the *Aframomum* species are still harvested from the wild. However, this is not sustainable since some of these feral species can easily be harvested to extinction without their full potentials being discovered and exploited. Therefore, given the leads provided by *A. melegueta*, there is an urgent need to bioprospect the clearly numerous other species of this genus and study their ecologies as well as methods of domesticating these important biological resources for sustainable exploitation. Based on chemotaxonomic relationships, plants of the same genus are likely to have similar chemical constitutions.

Most often only the seeds of these plants are used for medicinal, culinary and pesticidal purposes understandably because the seeds often harbour the highest concentration of whatever

bioactive ingredients. To minimize demand for the seeds for the various uses, it will be important and expedient to screen other parts of the plants especially the leaves as possible sources of potent pesticide compounds for purposes of sustainability. Several of the studies conducted on these plants have used either crude or partially purified extracts. It is therefore vital to carry out proper bioassay-guided fractionation of these extracts to identify the precise active ingredient(s), study their modes of actions as preludes to exploiting their synergistic, additive or potentiating effects. The properly studied bioactive constituents can then be employed as ecologically less disruptive, biodegradable, low-cost pesticides or as templates for novel synthetic chemicals.

Furthermore, knowing the precise identity of the active ingredients and their modes of action, proportional combinations of these plant derivatives with those of other plants with a different mode of action can be established. For example, in one of our studies, a proportional combination of 50:50% (1.5:1.5 g) *P. guineense* seed powder and ground dry cypress (*Cyperus aequalis* Vahl) leaves caused very high mortality of *Callosobruchus maculatus* weevils on cowpea seeds similar to 3 g of *P. guineense* powder used singly (Table 1). The combination significantly reduces the quantity of the relatively more expensive *P. guineense* used in the mixture i.e. significantly reducing the cost of the preparation while maintaining its potency. Such proportional combinations offer greater potential for large-scale exploitation since the mixtures are relatively cheaper and of greater quantities.

Given the highly aromatic nature of these plants and the proven efficacies of their derived essential oils, these oils can be distilled and used in large-scale insect control as green pesticides in like manner as those produced from other odorous plants like garden thyme (*Thymus vulgaris*), rosemary (*Rosmarinus officinalis*) and many others (Isman, 2004; Koul *et al.*, 2008). Prior to any large-scale exploitation of the oils, extracts and/or any other derivatives from the plants, appropriate efficacy and safety trials as well as studies to develop acceptable formulations and methods of standardization need to be carried out. However, since some constituents of plant-derived essential oils interfere with the octopaminergic nervous system unique to insects (Koul *et al.*, 2008), derivatives of these spices may not be toxic to humans and are hence potential sources of reduced-risk pesticides.

Some of the insecticidal and insect behaviour modifying compounds as well as antimicrobial constituents already identified from these tropical African traditionally used floras could be used as templates for structure activity studies to optimize their potencies and safety. For example, previous studies showed that different moieties attached to the piperidine ring conferred varied toxicities against *Aedes aegypti* (Pridgeon *et al.*, 2007). Such optimizations will likely produce more ecologically acceptable effective pesticides which can easily biodegrade into non toxic products.

Table 1: Cumulative percent mortality of adult *Callosobruchus maculatus* caused by treating 100 g stored cowpea grains with different combinations of *Piper guineense* and *Cyperus aequalis* powder or 0.05 g Actellic® dust

Treatment	Days exposed	Combination (g: g)							LSD (p = 0.05)
		0:0	0:3	0.5:2.5	1.5:1.5	2.5:0.5	3:0	0.05 actellic®	
<i>P. guineense</i> + <i>C. aequalis</i>	1	0±0.0	7.5±2.1	10.0±2.4	17.0±2.3	37.5±1.8	40.0±0.0	98.8±0.6	12.3
	2	0±0.0	17.5±2.0	27.5±1.6	37.5±1.9	66.3±1.3	38.8±1.2	100.0±0.0	10.8
	3	5±0.7	60.0±0.6	60.0±0.9	86.3±0.8	98.8±0.6	92.5±0.4	100.0±0.0	14.1
	4	10±0.2	75.0±0.8	81.3±0.6	92.5±0.3	100.0±0.0	97.5±0.6	100.0±0.0	12.6
	5	10±0.3	86.3±0.4	91.3±0.8	97.5±0.5	100.0±0.0	100.0±0.0	100.0±0.0	16.2

The current upsurge trends in demands for organic food products should serve as a market opportunity and as an impetus for the sustainable exploitation of these reduced-risk, eco-chemicals for the benefit of resource poor farmers in developing nations in particular and organic farmers in general. Due to their biodegradability and favourable safety profiles, these plant-based pesticides can play a vital role in achieving evergreen revolution (Dubey *et al.*, 2010).

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