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The Use of Botanicals as Pesticides: History, Development and Emerging Challenges

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Abstract

The unrestrained use of artificial pesticides over the years has strictly affected the function and dynamics of the ecosystem. The plants are a valuable store providing natural secondary metabolites that can be used as alternative pesticides that are non- pollutive, inexhaustible, everlasting, locally available, simply accessible, environment-friendly and comparatively profitable. It is against this background that scientists have made relentlessly effort to come up with botanicals that can be used as pesticides. The use of botanicals as pesticides has witnessed a rapid expansion in recent years. Plant extracts like nicotine were some of the earliest agricultural botanicals used as early as 17th century. An increasing number of experiments on bio-pesticides occurred in the rapid institutional growth of agricultural research of the early 20th century. Revival in academic and industrial research with a view to developing bio-pesticides transpired in response to increasing costs related with the overexploitation of artificial chemicals. The emergence of novel bio-pesticides has persistently increased since the mid-1990s. Nowadays more and better botanicals are used as pesticides. However, bio-pesticides o r botanicals have their limitations some of which include its slower rate of kill in comparison to orthodox chemical pesticides, shorter persistence in the environment and susceptibility to unfavourable environmental conditions. For effective use of bio-pesticides there is need for knowledge-intensive management systems. Plant protection biologists have a sole duty to facilitate an understanding of bio-pesticide efficacy and as well ensure that innovation and knowledge are properly disseminated towards the progress and implementation of sustainable approaches.

Keywords: Botanicals, Pesticides, Use, History, Development, Challenges

INTRODUCTION

The world population is increasing geometrically and the essentiality of food to cater for it is inevitable (Sadigov, 2022). Pests and diseases stand as bottlenecks against successful crop production (Agbenin *et al*., 2020). In attempt to reduce the menace of pests on crop production, crop producers both at subsistent and commercial or industrial levels, have over the years, employed pesticides as an alternative. Pesticides are chemicals or combination of chemicals that are applied to avert, terminate, deter, entice, disinfect, or reduce pests. A pest is a living

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entity which may be plant or animal that causes havoc to man or animals (Pathak *et al.*, 2022). Nonetheless, the persistent use and unrestrained utilization of pesticides has resulted in innumerable environmental and public health problems worldwide (Michael and Alavanja, 2009; Boedeker *et al.*, 2020; European Union, 2021; WHO, 2022). When used excessively, pesticides destroy several birds, aquatic and land plant and animal species as well as pose a serious threat to world security (Mahmood *et al.*, 2016; Gyawali, 2018; Assey *et al.*, 2021).

Quite a lot of studies have revealed that the practice of using artificial chemical pesticides has seriously impacted not only on abiotic but also on biotic components of the environment (Alengebawy *et al.,* 2021). The admission of chemical pesticides into the food chain and consequent bioaccumulation have caused a surge of unexpected outcomes (Hashimi *et al.*, 2020) which include soil and water pollution and reduction in the ozone layer (Wimalawansa and Wimalawansa, 2014; Pandiselvam et al., 2020). The practice of using pesticides randomly has resulted into undesirable effects on the environment like degradation, damage to unintended organisms, food and feed contamination due remnant of pesticides, reappearance of pests, genetic diversity in plants, as well as detrimental effects on biological diversity (Ngegba et al., 2022). In a report the World Health Organization indicated that 200,000 persons die a year world over due to chemical pesticides related consequences (Belmain, 2013; Eric, 2017) and that 97% of deaths due to Covid 19 were registered in countries that use chemical pesticides most (Craven, 2022). The negative effects due to mismanagement and abuse of chemical pesticides have impelled for substitute pest control solutions. Botanicals or bio pesticides offer an environmentally friendly substitute to the conventional pesticides (Ahmed et al., 2021).

Botanical Pesticides

The National Institutes of Health (2020) defined botanical as a plant or plant part valued for its medicinal or therapeutic properties, flavor, and/or scent. Bio pesticides are organic products that are used as an efficient arsenal against bacteria, fungi, nematodes, viruses and insect pests (Ahmad et al., 2017; Lengai et al., 2020). They are plant by products that are used to keep away, retard growth or exterminate pests (Hikal et al., 2017). Botanical pesticides are highly composed of secondary metabolites like alkaloids, steroids, resins, tannins, terpenes, flavonoids, and phenols that are antioxidants and have the ability to attack and destroy fungi, bacteria, and insect pests (Ahmad et al., 2017). Bio pesticides are derivatives of plants belonging to different families and are used in the form of plant extracts, essential oils or twain (Ni et al., 2021; El Khetabi et al., 2022). In the course of forming bio pesticides, parts of plants such as leaves, flowers, fruits, seeds, seeds, cloves, roots, stems and rhizomes are employed bearing in mind the bioactive compounds intended to be exploited and their availability in a particular biosphere (Ogunnupebi et al.,2020). The parts of plant to be used are first dried and grounded into fine powder before they are extracted with organic solvents in order to maximize extraction of the intended compounds (Chougule and Andoji, 2016) after which extraction, concentration, formulation and evaluation for efficacy in laboratory, controlled or field conditions follow (Zarubova et al., 2014).

Several studies have reported the existence of bioactive compounds in the plant families of Myrtaceae, Lauraceae, Rutaceae, Lamiaceae, Asteraceae, Apiaceae, Cupressaceae, Poaceae, Z ingiberaceae, Piperaceae, Liliaceae, Apocynaceae, Solanaceae, Caesalpinaceae, Sapotaceae (J naid *et al*., 2016; Lengai *et al*., 2020). Botanical compounds that are reported to be active against pests and which have been so far isolated include pyrethrin from pyrethrum (*Tanacetum cinerariifolium*), azadiractin from neem (*Azadirachta indica*) (Castillo-Sánchez *et al.*,

2015) and garlic (*Allium sativum*), turmeric (*Curcuma longa*) rosemary (*Rosmarinus officinalis*), ginger (*Zingiber officinale*) and thyme (*Thymus vulgaris*) (Lengai *et al*., 2020).

Development in the Use of Botanical Pesticides
Plants have been used in the protection against insect pests in the last 3000 years (Pavela, 2016). Botanical insecticides have been used in crop protection since the beginning of agriculture (Yadav *et al.,* 2022). Ancient Chinese, Egyptians, Greeks, and Indians are reported to have used botanicals in controlling pests of agricultural importance for over two thousand years (Dougoud *et al.,* 2019; Iqbal, 2021). The ancient people have known the idea of using compounds from plants as repellants against pests. For example, herbs like rosemary, myrrh and juniper were used by Ancient Romans to fumigate storehouses for threshed grains, in addition to looping aromatic plants at entrance holes leading to such storehouses or granaries to ward off pests (Kandar, 2021). Simultaneously, poisoned baits prepared as decoctions of *Helleborus niger* L. roots were commonly used to keep away rodents (Pavela, 2016; Yadav *et al.,* 2022). The Persians were reported to have used several plant oils to remedy scabies caused by an itch mite (Sarcoptes scabiei L) (Grdiša & Gršić, 2013; Shiven et al., 2020).In 400 B.C., the Persians deloused (treat a person or animal to rid them of lice and other parasitic insects) children using a powder collected from the dry flowers of a dalmatian plant or pyrethrum (*Tanacetum cinerariaefolium* (Trevir.) Sch.Bip) (Silva-Aguayo, 2023).

Different tribal or traditional cultural groups around the world were reported to have used extracts from plants, parts of plants or the whole plants for centuries (Grdiša and Gršić, 2013; Pavela, 2016; Souto *et al*., 2021). Subsistence and transitional farmers still use botanicals in the traditional pest management to protect crop both in the field and under storage condition (Belmain *et al*., 2013; Dougoud *et al*., 2019). The use of plant insecticides against pests by Ancient Romans were documented as early as 400 B.C. (Dayan *et al*., 2009). References were made to the use of sabadilla, neem, and pyrethrum as botanical insecticides for quite a long time (Isman and Machial, 2006; Grdiša and Gršić, 2013; Lengai *et al*., 2020).

Plant extracts like nicotine and other nicotine compounds were utilized as insecticides and fumigants against aphids, thrips, and mites as early as 17th century (Grdiša and Gršić, 2013; Shivkumara *et al*., 2019). Improvements in chemistry led to the popular use of better-defined plant extracts of derris, nicotine or quassia around 19th and early 20th centuries (Dayan *et al*., 2009; Grdiša & Gršić, 2013). The Croatians were reported to use powdered flowers of the Dalmatian pyrethrum to protect their farm produce and their houses (Lybrand *et al*., 2020). Indians have been using neem for centuries (Lybrand *et al*., 2020). The use of rotenone, a type of isoflavonoid which is commonly obtained from species of Derris, Lonchocarpus and Rhododendron, has been reported in South America, East Indies and Malaya (Souto *et al*., 2021). Sabadilla (*Schoenocaulon officinale* (Schltdl. & Cham.) A. Gray ex Benth) was used in folk medicine and natural insecticide ever since ancient times (Calles *et al*., 2008; Lengai *et al*., 2020). Sabadilla was observed to impair the function of motor, sensory and respiratory nerve by paralyzing and ultimately killing caterpillars, leafhoppers, thrips, stink bugs, and squash bugs (Stanojkovic *et al*., 2013; Ahmed *et al*., 2021).

The beginning of 20th century has witnessed rapid institutional growth in agricultural research and thus a snowballing growth on experiments on bio-pesticides (Kumar *et al*., 2021). Besides, revitalization in academic and industrial research in response to increasing costs due to overutilization of artificial chemicals was also registered (Bisht and Singh-Chauhan, 2020). The advent of new biopesticides has insistently intensified since the middle of 1990s (Samada & Tambunan, 2020). Currently, more and improved botanicals are used as pesticides that can contest with, as well as counterpart conventional chemical pesticides (Ngegba *et al.*, 2022). Over the past few years, synthetic insecticides are being replaced with botanicals which are naturally occurring insecticides obtained from plants in the form of plant-based extracts and essential oils possessing bioactive chemicals that are used for managing insect pests (Magierowicz *et al.*, 2020) and also abate plant parasites like fungi, bacteria, viruses and nematodes (Feyisa *et al.*, 2015). Quite a lot of studies have been done to find out the exploited and unexploited plant species that possess pest-killing attributes (Jawalkar *et al.*, 2016).

Application of Botanical Pesticides

Several bio pesticides have been found, nonetheless substantial quantities await identification of their bioactive ingredients after been isolated and analyzed. A lot of research on the use of botanicals as pesticidal agents and how efficient they are as substitutes to conventional pesticides has been done. Consequently, botanicals are now used as insecticides, nematicides, fungicides, bactericides, and virucides (Ngegba *et al.,* 2022). Currently, about 175 bio pesticides are registered worldwide, with about 700 active substance products available for use commercially (Dhakal and Singh, 2019; Samada and Tambunan, 2020). Bio pesticides can be categorized into the following based on the type of pest or organism they are targeted at.

Botanical Insecticides

Pests of common bean (*Phaseolus vulgaris* L.) like thrips, bollworm, armyworms, cabbage loopers, common grasshoppers, pink stalk borer, aphids, bean leaf spot, bruchid beetle and caterpillars are now managed by botanical pesticides such as *Tagetes minuta, L. camara, Mirabilis jalapa, R. speciose, A. indica, A. sativum, C. cinerariaefolium, Datura metel, Hyptis suaveolens, L. camara, Mirabilis jalapa* and *R. speciose* (Karani *et al.*, 2017). Extracts of *Carica papaya* L. and *Tagetes minuta* are known for their potency in suppressing abundant aphids that damage and destroy plant leaves (Murovhi *et al.*, 2020). Azadirachtin shows manifold forms of action, which involve reduced growth, oviposition repulsive, antifeedancy, harmful consequences on morphology, change in biological fitness, fertility suppression and sterilization (Zhang *et al.*, 2018). For example, it was reported that azadirachtin has lethal effect on pupal stage and the ability to significantly cause damage in the morphology of *Drosophila melanogaster* at an adult phase (Boulahbe *et al.*, 2015).

Ten percent (10%) turmeric dust, in laboratory condition, was reported to induce 80% mortality in rice pests such as *Cnaphalocrosis medinalis* and *Oxya nitidula;* eggplant pests such as *Aphis gossypii, Coccidohystrix insolitus, Epilachna vigintioctopunctata,* and *Urentius hystricellus;* and okra pests like *Amrasca devastans, Anomis flava, Dysdercus cingulatus, Earias vittella, Oxycarenus hyalinipennis, S. litura, and Tetranychus neocaledonicus* (Sankari and Narayanasamy, 2007; Ngegba *et al.,* 2022).

Botanical Fungicides

Plant-based bioactive compounds like alcohols, alkaloids, phenols, tannins, and terpenes are reported to delay sporulation, DNA, and protein synthesis in fungal pathogens (Yoon *et al*. 2013; Lengai and Muthomi, 2018; Lengai *et al*., 2020). In addition, they reduce their fungal pathogenicity consequent to hypha and mycelia alteration. Ultimately, they inhibit the production of toxic substances from mycotoxin-producing fungi such as *Aspergillus* spp. and *Fusarium* spp. (Lengai and Muthomi, 2018; Loi *et al*., 2020). Furthermore, efficacy of extracts of pawpaw leaves at 20, 40, 60, and 80% concentrations against *Alternaria solani* has been documented (Suleiman, 2010; Sowley *et al*., 2013; Pandukur and Amienyo, 2016; Ganiyu *et al*., 2018; Ngegba *et al*., 2022). Extracts from *Cassia alata*, *Alchornea cordifolia*, and *Moringa oleifera* were found to effectively reduce the prevalence of tomato fruit rot in many parts of Africa (Enikuomehin and Oyedeji, 2010; Behiry *et al*., 2022). Blight of potato (*Phytophthora infestans*), and Fusarium wilt (*Fusarium oxysporum*) of legumes were observed to be respectively mitigated through the application of botanical pesticides such as compost tea, and isolates of Pseudomonas and Bacillus genera isolated from rhizosphere (Karimi *et al*., 2012; Islam *et al*., 2013; Venkataramanamma *et al*., 2022). Allicin (allyl thiosulfinate)- an oily, slightly yellow liquid that gives garlic its distinctive odour, was reported to disrupt fungal morphology resulting into collapsing, thinning, and destruction of hyphal strands and ultimately obstructing germination of spores and hyphal growth (Perelló *et al.,* 2013; Burian *et al*., 2017; Sarfraz *et al*., 2020; Soteyome and Theeramongkol, 2023).

Botanical Bactericides

Botanicals that exhibit anti-bacterial properties include acetone extracts from *Aloe vera,* which has been found, to efficiently kill or significantly decrease or eradicate the growth of *Pseudomonas aeruginosa* (Goudarzi *et al.,* 2015; Abdissa *et al.,* 2017; Chassagne *et al.,* 2021) that causes diseases in plants and animals including humans (Diggle and Whiteley, 2020). An annual shrub like plant, *Datura metel,* commonly called Indian thornapple, and containing daturilin (withametelin)- a natural sterol lactone derived from the leaves of Datura genus, has been reported to have an efficacy against *Rhizoctonia solani* and *Xanthomonas oryzae* pv. *oryzae;* and thus, decreasing bacterial leaf blight of rice in greenhouse (Sateesh *et al.,* 2004; Meena et al., 2013; Sharma et al., 2021). Potato plants are effectively protected from bacterial wilt caused by a pathogenic bacteria called *Ralstonia solanacearum* through application of aqueous extracts of *Hibiscus sabdariffa, Punica granatum,* and *Eucalyptus globulus* in both greenhouse and field trials (Hassan *et al.,* 2009; Chen *et al.,* 2020). *Pseudomonas syringae* pv - a bacterial strain that can infect a wide range of species, *Xanthomonas vesicatoria* - a bacterium that causes bacterial leaf spot (BLS) on peppers and tomatoes, and *Clavibacter michiganensis* subsp - that cause bacterial canker of tomato; are all effectively inhibited by extracts of extract of *Allium sativum* (Balestra *et al.,* 2009; Chen *et al.,* 2018; Siddiqua *et al.,* 2023). Oils of thymol, palmarosa, and lemongrass were found to inhibit the growth and thus reduce the incidence of *R. solanacearum* race 4 (phylotype I), (Ji *et al.,* 2005; Hong *et al.,* 2011; Ganiyu *et al.,* 2020) and the occurrence of bacterial wilt in edible ginger (Paret *et al.,* 2010; Aysanew and Alemayehu, 2022), and inhibited the severity of bacterial wilt of sweet peppers (Alves et al., 2014; Abd-Elrahim et al. 2022) when used as soil fumigants (Ji et al., 2005; Ganiyu et al., 2020).

Botanical Nematicides

Essential oil extracts derivative of pesticidal plants are reported to kill root-knot nematode *(Heterodera cajani)* at juvenile developmental stage (Singh *et al.,* 2001; Faria and Vicente, 2021). Moreover, cytoplasmatic membrane of nematodes are reported to be broken down by lipophilic phytochemicals and as a result of which it deters protein structures known to enhance growth and development essential for life continuity (Pavaraj *et al.,* 2012; Desmedt *et al.,* 2020; Sasanelli *et al.,* 2021). Reports indicated that farmers utilized the crushed leaves of African 17 marigolds in managing nematodes (Pesticide Action Network, 2005; Karakas & Bolukbasi, 2019). The use of *Lantana camara* and *Trichoderma harzianum* in controlled condition was observed to repress masses of eggs, formation of gall, as well as reproduction in root-knot nematodes of tomato crops (Feyisa *et al.,* 2015; d'Errico *et al.,* 2022; Nafady *et al.,* 2022). In the meantime, bioactive compounds such as glycosides, tannins and alkaloids, were reported to cause reduction in the quantity of hatched eggs, agility, and resulting in mortality of young root knot nematode in secondary growth phase (Akyazi, 2014; Asif *et al.,* 2017; Desmedt *et al.,* 2020; Mwamula *et al.,* 2022). Extracts of active compounds from plants like common Myrtle *(Myrtus communis)* were reported to paralyze and reduce infection potential of young root-knot nematodes (Oka et al., 2012; Kundu et al., 2021). Simlarly, in a greenhouse experiment, Khan et al. (2019) reported that aqueous extracts of *C. grandis, C. benghalensis, L. cephalotes, P.*

amarus, and *T. portulacastrum* had high nematocidal efficacy on egg-hatching and death rate on M. incognita at an early developmental stage (Ngegba et al., 2022).

Botanical Viricides

The antiviral potentials of some medicinal plants have been reported in literature. These plants induce systemic resistance of the host plants with antivnbiral properties by impeding the spread of viruses and killing insect vectors (Mukhtar *et al.*, 2008; Waziri, 2015; Manjunatha *et al.,* 2022). Besides, botanical viricides are reported to impede hemagglutination, activity of enzymes, and virus penetration and replication (Rajasekaran *et al.,* 2013, Kohn, 2015). An acetone extracts from cottonseed oil was discovered to be highly effective against tobacco mosaic virus (TMV) during a laboratory experiment, and against Rice Stripe Virus (RSV) and southern rice black streaked dwarf virus (SRBSDV) under field experiment (Zhao *et al.,* 2015; Lengai *et al.,* 2020). Bio-active extracts from *Theileria orientalis,* commonly known as Indian charcoal-tree, or pigeon wood, were found to repress the propagation of mosaic virus of watermelon. The extracts caused a decline in viral infection on the hypocotyls by halting the liberation of nucleic acids (Elbeshehy *et al.,* 2015; Ahmed and Qasem, 2017). Additionally, extracts from *Eucaluptus camaldulensis, Clerodendrum aculeatum, Haplophyllum tuberculatum, M. jalapa, Potentilla arguta, Boerhaavia diffusa, Sambucus racemose,* and *T. orientalis* were reported to have high efficacy against plant viral infection (Abdelkhalek *et al.,* 2020a; Abdelkhalek *et al.,* 2020b).The spread of leafroll virus of potato plants was found to be halted by 63.6 and 81.72 % with the application of 6 g/L *Artemisia campestris* and *T. orientalis,* respectively (Al-Ani *et al.,* 2010; Elbeshehy *et al.,* 2015; Ngegba *et al.,* 2022).

Emerging Challenges

In spite of the taut contest between botanicals and chemical pesticides, the bio-pesticides are not common sight in the market today (Kekuda *et al.,* 2016; Kumar *et al.,* 2021). In addition, bio-pesticides have short shelf-life spans as a result of their sensitivity to fluxes in temperature and humidity (Kumar *et al.,* 2021; Ayilara *et al.,* 2023) and thus their active ingredients are easily degraded (Lengai *et al.,* 2020) and consequently are not easy to be standardized as a result of differences in growth, habitat, variety, harvest period, storage condition due to the plant, and the method of extraction due to the botanical to be applied (Dayan et al., 1992; Ngegba *et al.,* 2022). Moreover, most botanical pesticides are structurally complex (Acheuk e*t al.,* 2022) and are hard to be manufactured and their costs of synthesis are too high (Guleria and Tiku, 2009; Garcia, 2020; Ngegba *et al.,* 2022; Iqbal et al., 2022). Some farmers think that botanical pesticides do not work at all because they take more time to act than synthetic pesticides (Ratto *et al.,* 2022) and do not completely get rid of pests (Constantine *et al.,* 2020). Additional limitations associated with the use of botanical pesticides include the need for several number of sprays and the brief residual time (Ratto *et al.,* 2022) and the issue of arriving at a suitable formulation due to the fact that a number of plant-derived compounds, varying in chemical properties, are found to be present in one plant species (Kumar and Singh, 2015; Borges *et al.,* 2018; Ngegba *et al.,* 2022).

Furthermore, there are problems related to the marketing of botanical pesticides, which include short supply of the raw materials required to produce the botanicals (Guleria and Tiku, 2009; Okrikata and Oruonye, 2012; Isman, 2020) and high cost experienced in the toxicological evaluation of the botanical pesticides (Fischer et al., 2013; Akaike and Izumi, 2018; Shivkumara *et al.,* 2019). Active ingredients in the botanicals are subjected to poor quality control and standardization procedure (Ivase *et al.,* 2021). Additional bottleneck is the dearth in the field-based data and lack of demonstrations on the effectiveness, application and cost-effectiveness of botanicals in pest control (Okrikata and Oruonye, 2012; Borges *et al.,* 2018; Lengai *et al.,* 2020).

CONCLUSION AND RECOMMENDATIONS

The use of botanical pesticides to manage agricultural pests has been in existence for centuries. The continual management of agricultural pests that are economically significant by the application of botanical pesticides is believed to be successful and efficient due to their ability to undergo renewal, keep the environment safe, and their role in human welfare. Moreover, the predominant application of botanicals to manage agricultural pests in developing nations is attributable to their obtainability, user-friendliness, manageableness, and profitability. However, efforts at unearthing the biologically active ingredients from botanical pesticides are still in its elementary stage. Today, efforts aimed at promoting the categorization of effective plant-derived chemicals and their concentrations in finished products are stagnated by the issues of standardization and precision. Consequently, for improving and encouraging the robust application and implementation of botanical pesticides as tolerable, harmless, and maintainable products for pest control, we put forward the following recommendations: In lieu

i. It is a known fact that botanical pesticides are synthesized from plant- derived raw materials, and these plant sources may not necessarily be available year-round; and their demand might also be high due to an increasing shift to the use of botanicals in place of synthesized pesticides. Hence, there is need for these plant sources to be domesticated substantially, so as to cater for such increasing demand.

ii. Problems associated with the use of botanical pesticides which include identif ication of suitable formulation, discovering the bio-active ingredients, knowin g the required rate of application, identifying the periods of storage for stabili ty, and instability in ultraviolet condition; when adequately addressed throug h research can unequivocally improve marketing of these products.

iii. Up to this time there are few botanicals in our markets probably due to their high cost of production, unavailable plant sources, etc., therefore, there is a ne ed for collaborative efforts from various stakeholders including farmers, vendors, manufacturing-companies, depositors, and scientists, with a view to coming up with strategies for accelerating the infiltration of botanicals in our markets.

iv. Bottlenecks related to regulatory measures, that are known to be a stumbling block against the botanical pesticide- entreprise, when properly addressed could make the business of botanicals more practicable and inexpensive and thus promoting entrepreneurship, investment, funding of botanical pesticide-based research.

v. Low-income farmers and extension workers should be trained regularly on th e skills required for sustainable production and application, and on how to circulate knowledge on the use of botanical pesticides.

vi. The systematic shift to the use of botanicals needs sensitization. Concerned government agencies should stage campaigns towards educating farmers and manufacturers on the need and suitability of botanical pesticides in achieving a Workable Pest Management Strategy.

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