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Biocide Potential of *Jatropha curcas* L. Extracts

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Abstract

Jatropha curcas L., a multipurpose oilseed plant, is very important for biodiesel production; it also has a wide range of bioactive compounds with medicinal properties and biocidal activity for control of crop pests and diseases. This review presents the state-of-the-art of the biocidal activity of *J. curcas* extracts. Chemical constituents such as phorbol esters are responsible for high bioactivity of *J. curcas*, due to their toxicity to humans and animals and to their high fungicidal and insecticidal activity. The fungicidal activity of these constituents may be due to destroy endoplasmatic reticulum and hyphae cell walls. The activity of these compounds on insect pest metabolism is well known, leading to an antifeedant effect, repellency, mating inhibition, oviposition inhibition or suppression and/or induction of infertile egg production, and inhibition of larva, nymph, and pupa development. Several studies have shown that although all organs of *J. curcas* plant are toxic, the degree of toxicity varies in accordance with the extract formulation, the nature of the active substance, the administration rate and procedure, and the individual sensitivity of pests and diseases. Thus, *J. curcas* stands out as a promising species for bioenergy purposes, as well as for control of pests and diseases that affect agriculture production.

Keywords: plant pathogens, insect pests, secondary metabolites, physic nut

1. Introduction

The *Jatropha* genus (Euphorbiaceae - Platiobeae subfamily) has more than 70 shrub-like species, such as *J. pohliana*, *J. gossypiifolia*, and *J. curcas* (Xu et al., 2012). Fast growth, easy propagation, and adaptation to many environments are some of the traits that favor wide distribution of the plants of this genus. *J. curcas*, commonly known as physic nut, is a diploid species of 22 small chromosomes (Dahmer et al., 2009). The inflorescences with male or female (and occasionally hermaphrodite) flowers give rise to fruit with three seeds (trilocular ovary). The stem with multiple branches holds inflorescences, which appear at the beginning of the rainy season. As a shrub species, it reaches 5 m height, while the root system reaches 5 m depth, with a primary root and four lateral roots (Brasileiro et al., 2012; Divakara et al., 2010). Studies have confirmed that the center of origin, diversity, and domestication is Mexico, as suggested by (Dias et al., 2012), although it can be grown throughout the world and in all regions of Brazil (Heller, 1996). *J. curcas* is widely distributed and is found at altitudes ranging from sea level to 3000 m, in regions with annual rainfall from 250 to 2500 mm. It requires a temperature between 18 and 28 °C (Dias et al., 2012). As a hardy oilseed plant that develops under adverse dry and rocky soil conditions, it may be useful for recovery of degraded areas.

An additional advantage of *J. curcas* is its perennial cycle and high yield as a crop; it may yield more than 1500 L ha^{-1} of oil after the fourth year of cultivation (Oliveira, 2016; Laviola et al., 2014; Dias, 2007). *J. curcas* and palm species such as oil palm (with production of around 4000 L ha^{-1} of oil) offer considerable promise for biodiesel production. Soybean, currently the crop of choice for most Brazilian biodiesel production (70%), yields 500 L ha^{-1} of oil (ABIOVE, 2019; Oliveira, 2016).

The ominous consequences projected in a scenario of global climate changes and the gradual reduction in petroleum reserves drive the search for alternatives to supply world demand for transportation energy. Priority should be placed on available sources of energy that are economically feasible, socially just, and ecologically correct. Liquid biofuels, ethanol and biodiesel, can be considered in this context (Dias, 2011; Ribeiro et al., 2011). The biodiesel derived from transesterification of plant oils is an environmentally sound alternative since it is a renewable source of energy that may be used to complement petroleum diesel (Roque et al., 2017). The use of biodiesel reduces release of greenhouse gases from burning of fossil fuels and reduces petroleum dependency. *J. curcas* offers the most positive balance among the bioenergy crops that have considerable potential for fuel oil production, both in terms of high oil production per hectare (38% oil in its seeds, with a mean of 1500 L ha^{-1}) and of lack of competition with the food chain, as occurs for other oilseed crops (Dias et al., 2012; Dias, 2011; Ribeiro et al., 2011; Dias, 2007). These characteristics make this species a great green promise for biodiesel production, in spite of the scarcity of improved varieties and the present heterogeneity of the cultivated population (Oliveira, 2016; Dias, 2007).

J. curcas has been known from antiquity for its exceptional medicinal properties (Dias et al., 2012). This characteristic is even responsible for its name: the Greek word ***jatrós*** means doctor, and ***trophé*** means food (Kumar and Sharma, 2008). Studies report its healing

(Sachdeva et al., 2011), anticarcinogenic (Devappa et al., 2011), antidiabetic (Jayakumar et al., 2010), and anti-inflammatory (Nayak and Patel, 2010) activities. However, its seeds and oil must be used with caution since they have an array of compounds understood to be antinutritional; its oil and pressed residues are inappropriate for animal and human consumption. This toxicity arises from the presence of compounds such as protease inhibitors (curcine), phytates, lectins, saponins, and even more toxic compounds, such as co-carcinogens and phorbol esters (Devappa et al., 2012; He et al., 2011; Haas and Mittelbach, 2000).

The array of products obtained from *J. curcas* has increased, highlighting the multipurpose nature of the species. Extracts from oils of the seed, leaf, and stem have exhibited not only medicinal properties but also molluscicide, insecticide, and fungicide activities (Saetae and Suntornsuk, 2010), with possible future use as a biocide. In most cases, pests and diseases are currently controlled through intensive and indiscriminate use of synthetic insecticides and fungicides. This strategy leads to selection for pesticide-resistant populations, making control ever more difficult, less efficient, and, consequently, more costly. Organochlorides and organophosphates are the most common chemical groups of synthetic pesticides. Pesticides with low toxicity, persists in the human body and in the environment and may remain active for a considerable time. Whereas the biocides though quickly degraded in the environment (Moragas and Schneider, 2003). Plant-derived biocides clearly provide bioactive substances for integrated pest and disease management programs, and they may reduce undesirable effects from application of organo-synthetic products in the environment (Sharma, 2017; Ashraf et al., 2014). They have even greater specificity for target organisms (Sharma, 2017; Ashraf et al., 2014) and have lower production cost, making the final product economically feasible for small farmers.

The aim of this review is to offer a broad perspective on the state-of-the-art of the biocide activity of *Jatropha curcas* L extracts.

2. Main Metabolites of *J. curcas* for Pest and Disease Control

Compounds arising from chemical reactions within a cell are called metabolites (Simões et al., 2010). In accordance with their distribution in the plant kingdom and their participation in vital processes, they may be divided into primary and secondary metabolites. Primary metabolites are essential to life and common to all plants. They perform some functions in transformation of molecules, such as photosynthesis and amino acid and protein synthesis (Simões et al., 2010).

Secondary metabolites are organic compounds produced by plants which are not directly involved in the normal growth, development, or reproduction of plants and they contribute to plant adaptation and survival (Simões et al., 2010). They play an important role in plant-environment interactions, including the plant-pathogen interaction. Since they are not ubiquitous, they are often used as defining traits in taxonomy. Most secondary metabolites are biosynthesized from intermediates provided by primary metabolism. These intermediates are used as precursors in the biosynthetic routes of aliphatic amino acids, malonate, acetate, mevalonate, deoxyxylulose phosphate, shikimate, and aromatic amino acids, culminating in the formation of secondary metabolic compounds (Leite, 2009). Secondary metabolites are of great interest, not only because of the biological activities of plants in response to environment but also because of it immense pharmacological activity. Many metabolites have significant agronomic value (Simões et al., 2010). All plant extract activities originate from their evolutionary history. Plants have developed their chemical defenses and enhanced their defense mechanisms through pathways that synthesize these compounds (Wiesbrook, 2004). These substances exhibit biological activity, including activity on microorganisms through diverse mechanisms.

J. curcas is an important species for analysis of secondary metabolite production and these compounds are distributed in all its organs. Like other plants of the Euphorbiaceae family, it produces a great deal of latex, and its metabolome (Van den Berg et al., 1995) and proteome (Yang et al., 2017) exhibit a great variety of primary and secondary metabolites. However, phorbol esters are the most prominent toxic compound. It can cause acute toxicity, provoking an intense inflammatory response, and/or chronic toxicity. It prompts the appearance of tumors by the kinase C enzyme bonding and activation mechanism, responsible for cell differentiation and for promoting growth regulation (Abdelgadir and Van Staden, 2013; Goel et al., 2007). Six different derivations of phorbol esters have been identified in this species (Haas et al., 2002). These metabolites are sources of bioactive substances compatible with integrated pest and disease management programs. For that reason, it may be possible to combine them with other methods for control of insects, bacteria, and fungi, allowing maintenance of ecological balance without leaving harmful residues (Trivedi et al., 2018; Patil et al., 2016). Biocides constitute an excellent alternative because they are natural products derived from plants and produced by plants or derived from plants through aqueous extractions or extractions with organic solvents (Wiesbrook, 2004).

J. curcas plant is highly toxic as a whole, not only to microorganisms but also to animals and humans. All parts of the plant are toxic, and the degree of toxicity varies according to the extract, the chemical composition of the extracted substance, the environment, and the rate and mode of application. Toxicity can be also influenced by the individual sensitivity of an organism (Devappa et al., 2010). Curcine, the protein present in *J. curcas* seeds, for example, has expressive antifungal activity, and may completely inhibit the formation of spores of *Pyrucularia oryzae*, a fungus that damages the rice crop. However, this substance may inhibit protein synthesis processes in animals (Jaramillo-Quintero et al., 2015; Wei et al., 2004). 2S albumin is another example of a molecule present in *J. curcas* with diverse effects. It may cause adverse effects due to allergenic activity and may bring about skin and eye irritation (Machado and Silva, 1992). Other compounds, such as phytates and saponins, also require precautions (Wei et al., 2004). These metabolites must be used with care. In integrated pest and disease management, phorbol esters are key molecules, due to their antifungal activity (Saetae and Suntornsuk, 2010) and toxicity to some insect pests (Ratnadass et al., 2009).

As seen above, *J. curcas* is a potential producer of bioactive secondary metabolites of the most diverse types (Abdelgadir and Van Staden, 2013; Sabandar et al., 2013). This considerable potential should be studied and used to advantage in all areas, particularly in agriculture.

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3. Pests and Diseases Controlled by Extracts of *J. curcas*

Extracts derived from the leaves, stems, roots, and seeds of *J. curcas* exhibit diverse properties for pest (Table 1) and disease (Table 2) control in plants. The efficacy of *J. curcas* extracts as a biocide has been confirmed in various studies (Sharma, 2017; Ogbebor et al., 2007; Adebowake and Adedire, 2006) and their application is a useful alternative from an agronomic perspective, considering resistance of some pests and pathogens to synthetic insecticides and fungicides. Integrated management programs have encouraged this alternative control measure to minimize ecological damage found in ecosystems since natural products are innocuous to the environment (Trivedi et al., 2018; Patil et al., 2016).

Table 1. Different parts and extracts of *Jatropha curcas* L. used in pest control

Insect	**Pest of**	**Solvent**	**Plant organ**	**References**
Aphis fabae Scop.	Cowpea	Ethanol	Oil from the seed	Botti et al. (2015); Habou et al. (2011)
Aphids crassivora	Cowpea	Acetone	Oil from the seed	Ahuchaogu et al. (2014)
Bactrocera zonata	Peach	Ethyl acetate; methanol	Oil from the seed; leaf; stem	Rampadarath et al. (2016)
Bactrocera cucurbitae	Melon	Ethyl acetate; methanol	Oil from the seed; leaf; stem	Rampadarath et al. (2016)
Brevicoryne brassicae	Cabbage	Water	Oil from the seed	Botti et al. (2015)
Callosobruchus maculatus	Cowpea	Water; ethanol; acetone	Oil from the seed	Boateng and Kusi (2008); Abdoul Habou et al. (2014); Ahuchaogu & Ojiako (2015); Opuba et al. (2018)
Ceratitis capitata (Wied)	Different kinds of fruits	Water	Leaf	Silva et al. (2015)
Clavigralla tomentosicollis	Cowpea	Ethanol	Oil from the seed	Katoune et al. (2011)
Cnaphalocrocis medinalis	Rice	Methanol; ethanol; petroleum ether	Oil from the seed	Dowlathabad et al. (2010)
Coptotermes vastator	Different kinds of timber	Crude oil	Oil from the seed	Acda (2009)
Helicoverpa armigera	Cotton	Water; methanol; ethanol; petroleum ether	Oil from the seed	Ratnadass et al. (2009); Dowlathabad et al. (2010); Ingle et al. (2017a)
Maruca testulalis	Cowpea	Acetone	Oil from the seed	Ahuchaogu & Ojiako (2015)
Megalurothrips sjostedti	Cowpea	Ethanol; acetone	Oil from the seed	Katoune et al. (2011); Ahuchaogu & Ojiako (2015)
Microtermes obesi	Different agricultural Plants	Butanol; ether; hexane; methanol	Leaf; root; stem bark	Verma et al. (2013)
Mussidia nigrivenella	Maize	Water	Oil from the seed	Agboka et al. (2009)
Odontotermes obesus	Different perennial crops	Methanol	Oil from the seed	Verma et al. (2011)
Odontotermes sp	Different stored crops and grains	Crude oil	Oil from the seed	Lateef et al. (2014)
Oecophylla longinoda	Different forest trees	Ethanol; acetone; water	Root; seed	Ojiako et al (2015)
Oligonychus coffeae	Different tea-growing	Crude oil	Oil from the seed	Roy et al. (2016)
Planococcus citri	Coffee	Water	Oil from the seed;	Holtz et al. (2016)

			leaf; stem; stem bark; fruit	
Schistocerca gregaria	Different kinds of crops	Hexane	Oil from the seed	Bashir & El-Shafie (2013)
Sitophilus granaries	Stored grains	Petroleum ether	Oil from the seed	Nabil & Yasser (2012)
Sitophilus oryzae L.	Rice	Chloroform; petroleum ether	Oil from the seed	Khani et al. (2011)
Sitophilus zeamais	Cereal seeds (rice, maize, etc)	Acetone; petroleum ether;	Oil from the seed; seed	Asmanizar & Idris (2011); Musa et al. (2011);
Spilarctia obliqua Walk	Oilseed crops, vegetables, and medicinal plants	Benzene	Leaf	Katiyar (2016)
Spodoptera frugiperda	maize, rice, sugarcane, cotton	Methanol	Oil from the seed	Devappa et al. (2012)
Spodoptera litura	Cotton, rice, tobacco, etc.	Methanol	Leaf; stem; seed; seed hull; root	Ingle et al. (2017b)
Tetranychus urticae	Okra	Water	Leaf	Premalatha et al. (2018)

The use of aqueous leaf extract killed *Ceratitis capitata* (fruit fly) larvae (Silva et al., 2015) and the insect pests *Sitophilus zeamais* and *Rhyzopertha dominica* in stored grain (Silva et al., 2012a). Promising results were also obtained from stem and leaf hydroalcoholic acidic extracts in control of *Aedes aegypti* larvae (Beserra et al., 2014). In the five extracts evaluated, the presence of proteins, amino acids, and polysaccharides were detected, as well as secondary metabolites such as tannins, phenols, alkaloids, steroids, and saponins (Silva et al., 2015; Beserra et al., 2014). The extract may sometimes prolong the larval phase of the pest insect, together with its mortality. This activity is very important in the field because it will increase exposure time of the pest to natural enemies and the mean time of each generation, with consequent reduction in population growth of the pest (Torres et al., 2001). Toxicity evaluation of methanol extracts from plant parts (leaf, stem, seed, and root) of *J. curcas* on the larval stages of *Spodoptera litura* showed that the leaf extract was most effective, with mortality rates of 60% (Ingle et al., 2017b). Similar results were observed from use of stem and seed (oil) extracts on larvae of *Bactrocera zonata* and *Bactrocera cucurbitae* (Rampadarath et al., 2016). The difference in effectiveness of the extracts was due to the differences in metabolite contents of various plant organs (Rampadarath et al., 2016). Methanol extract seed oil was able to control 100% of the population of adult individuals of the *Odontotermes obesus* termite (Verma et. al., 2011). This result is might be due to the presence of high concentration of phorbol ester in this extract.

In addition to the solvent and organ used in preparation of the extract, the method of application also is important so that control occurs in an efficient manner. For control of *Planococcus citri*, known as citrus mealybug, aqueous extracts of the stem and leaf were applied in two ways: 1) spraying the extract directly on the mealybugs with the Potter spray tower (direct application) and 2) application of the extracts on coffee leaf disks, with subsequent placement of the insects on it (indirect application). These forms of application represent post-infection and preventive control, respectively (Holtz et al., 2016). Direct application of stems and leaves extracts exhibited the best results.

Table 2. Different parts and extracts of *Jatropha curcas* L. used in control of fungal diseases

Fungi	Pest of	Solvent	Plant organ	References
Alternaria alternata	Cotton, rice, bean, etc.	Petroleum ether; water; methanol	Oil from the seed; leaf; stem (without bark); stem bark; root	Srivastava et al. (2012); Gaikwad et al. (2012); Sachdeva et al. (2011)
Aspergillus flavus	Garlic, rice, cacao, oats	Water; petroleum ether; ethanol; methanol; hexane	Oil from the seed; leaf; stem (without bark); latex; stem bark; root	Makun et al. (2011); Srivastava et al. (2012); Gaikwad et al. (2012); Bassey et al. (2013); El-Nour et al. (2015); Arekemase et al. (2011); Igbinosa et al. (2009)
Aspergillus niger	Lettuce, garlic, beet, soybean	Water; acetone; alcohol; methanol; petroleum ether; ethanol	Oil from the seed; leaf; stem (without bark); stem bark; root skin; root; calli	Ahirwar et al. (2015); El-Nour et al. (2015); Srivastava et al. (2012); Gaikwad et al. (2012); Bassey et al. (2013); Danish & Robab (2015); Igbinosa et al. (2009); Sahidin et al. (2011)
Cercospora coffeicola	Coffee	Ethanol	Leaf	Muniz (2019); Zaidan (2018)
Colletotrichum capsici	Pepper	Ethanol	Oil from the seed	Saetae & Suntornsuk (2010)
Colletotrichum gloeosporioides	Garlic, cacao, pea, etc.	Ethanol; water	Oil from the seed; leaf	Saetae & Suntornsuk (2010); Ogbebor et al. (2007); Li et al. (2006)
Colletotrichum musae	Banana	Water	Leaf	Thangavelu et al. (2004)
Curvularia lunata	Garlic, rice, potato	Ethanol	Oil from the seed	Saetae & Suntornsuk (2010)
Drechslera heveae	Rubber tree	Water	Leaf	Ogbebor & Adekunle (2008)
Fusarium oxysporium	Tomato, pepper, sugarcane, etc.	Water; alcohol; ethanol; petroleum ether; *Lectin protein	Oil from the seed; leaf; stem (without bark); stem bark, root	Córdova-Albores et al. (2014); Córdova-Albores et al. (2016); Saetae & Suntornsuk (2010); Al-Saman et al. (2015); Siva et al. (2008); Gaikwad et al. (2012); Bassey et al. (2013)
Fusarium semitectum	Soybean	Ethanol	Oil from the seed	Saetae & Suntornsuk (2010)
Fusarium solani	Potato, pea, bean, etc.	Water; ethanol; methanol; acetone: water	Oil from the seed; stem bark	Córdova-Albores et al. (2014); Igbinosa et al. (2009); Sachdeva et al. (2011);
Fusarium sp	A wide range of crops and vegetables	Water; acetone; alcohol	Oil from the seed; leaf; stem bark; root skin	Ahirwar et al. (2015)
Fusarium verticillioides	Rice, bean, maize	Water	Oil from the seed	Makun et al. (2011)
Lasiodiplodia theobromae	Avocado, pineapple, garlic	Ethanol	Oil from the seed	Saetae & Suntornsuk (2010)
Macrophomina phaseolina	Garlic, rice, potato	Water	Leaf	Savaliya et al. (2015)
Rhizoctonia solani	Lettuce, rice, oat	Water	Leaf; stem (without bark); root	Gaikwad et al. (2012)
Rhizopus sp	A wide range of fruits and vegetables	Water; acetone; alcohol; petroleum ether; methanol	Oil from the seed; leaf; stem bark; root skin	Ahirwar et al. (2015); Sahidin et al. (2011)

Plant-derived secondary metabolites might induce effects on insect metabolism and leads to an antifeedant effect, repellency, oviposition inhibition or suppression and/or induction of infertile egg production, inhibition of larva, nymph, and pupa development, and inhibition of mating (Hartmann, 2004). The superiority biocidal activity of *J. curcas* oil extracts might be related with the presence of pherbol ester at high concentration in the seeds (Gonçalves et al., 2009). Application the extracts directly was more efficient than their application indirectly, since extract molecules are absorbed by integuments of insects, affecting their central nervous system and leading to their death. In indirect application, these molecules first pass through the digestive system of the insect before reaching vital systems (Holtz et al., 2016).

Extracts from different parts of *J. curcas* plant also proved to have a fungicidal effect (Table 2). In the banana crop, aqueous leaf extract was effective in control of the fungus *Colletotrichum musae*, the agent of anthracnose, through inhibition of mycelial growth (Thangavelu et al., 2004). In recent studies, ethanolic extract from *J. curcas* leaf reduced the mycelial growth of *Cercospora coffeicola*, by up to 20%, and completely inhibited germination of *Hemileia vastatrix* (Muniz, 2019; Zaidan, 2018).

In ornamental *Gladiolus* plants, *Fusarium oxysporum* f. sp. *gladioli* is a main pathogen that affects its production. Systemic fungicide applications are the common method of control. *J. curcas* oil, extracted by petroleum ether, was tested for control and caused changes – in the morphology of the inner lining of the mycelia and of the conidia, in the presence of vacuoles, and in inhibition of the metabolic activity of the membrane in the *Fusarium oxysporum* (Córdova-Albores et al., 2016). Although these results did not bring about effective control of the fungus, they are important, due to their effect on the fungal reproductive structures and on the life cycle of the fungus.

Possible mechanisms of antifungal activity are destruction of the cell walls of the hyphae (Wei et al., 2005) and of the endoplasmatic reticulum (Jing et al., 2005). Most of the cell organelles had been destroyed up to 72 h after the treatment with Jatropherol-I, a phorbol-type diterpene from *J. curcas* (Jing et al. 2005), and β-1,3-glucanase, a protein isolated from *J. curcas* (Wei et al., 2005). Unlike what was observed for insect pests, antifungal activity comes from extracts derived from each *J. curcas* plant organ, showing the importance of substances other than phorbol esters. Furthermore, it shows the greater sensitivity of these organisms because it is possible to obtain good results even from use of plant organs that have a lower concentration of the compound.

Ahirwar et al. (2015) found that extract of *J. curcas* using solvents with different polarities (i.e. petroleum ether, acetone, alcohol, water, ethanol, and methanol) resulted in different antifungal activities. The methanol extract generally has the best biocide activity, followed by ethanol and water. The varied effectiveness of the extracts can be explained by the uneven distribution of metabolites in plant organs and by metabolites themselves extracted as a result of solvent polarity. The highest concentrations were responsible for the best results.

In addition to the biocide activity reported above, studies indicated the allelopathic properties of different *J. curcas* organs against various plant species such as *Brassica napus* (Silva et al., 2012b; Antonelli et al., 2016), *Hibiscus esculentus* (Abugre and Sam, 2010; Abugre et al., 2011), *Helianthus annuus* L. (Silva et al., 2012b), *Phaseolus vulgaris* (Abugre and Sam, 2010), *Cichorium intybus* (Cremonez et al., 2013), *Capsicum annum* L. (Rejila and Vijayakumar, 2011), *Lycopersicon lycopersicum* (Abugre and Sam, 2010) and *Zea mays* L.

(Abugre and Sam, 2010; Silva et al., 2012b). The main allelopathic signals generated by *J. curcas* are reduction in root growth and changes in the fresh or dry matter weight of other species. In contrast, a positive allelopathic effect was observed when soybean (*Glycine max*) seeds were placed to germinate in the presence of the root exudate of *J. curcas* (Silva et al., 2012b).

4. Conclusion

Studies on extracts of *Jatropha curcas* have shown that this plant exhibits considerable promise for formulation of new biocides. The range of metabolites from *J. curcas* requires the use of solvents with different polarities so that all compounds are extracted in an efficient manner and then tested. Among the compounds with biocide effect, phorbol esters are most prominent because of their high toxicity to most pests and fungi. However, studies should be carried out particularly to test the activity of these compounds on plant pathogenic bacteria.

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