

# Chapter 5

## Dispersion and Increase of Natural Enemies in Agroecosystems



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### 5.1 Introduction

The dispersion capacity of natural enemies by biological control agents released or applied in cultivation fields as well as natural enemies, which inhabit the agroecosystem, is of great importance for the sustainability of pest management, because it facilitates their survival, establishment, and continuous activity, among other advantages. Therefore, the dispersion of entomopathogenic and entomophagous is an important factor that affects its establishment and its efficiency in pest suppression (McDougall and Mills 1997).

However, the expansion of an extensive and strongly industrialized agriculture has simplified the agricultural landscape to small fragments of the natural habitats. Habitat fragmentation can affect insect dispersal in the landscape, especially considering modern agricultural practices that modify the landscape significantly, eliminating natural or semi-natural vegetation where biological control agents may seek refuge (Grez et al. 2008).

The management of ecological corridors becomes possible to foment the biodiversity in the monoculture systems, improving the biological structure of the agroecosystems and facilitating the ecological control (Altieri and Nicholls 1994). The corridors structure is influenced by the management of the trees due to their utility in the conservation of the associated biodiversity, by providing habitats and preserving certain level of connectivity of the landscape (Harvey et al. 1999), that is, the continuity of a habitat or covering type through an area determined in the landscape (Turner et al. 2001). The connectivity implies the connection of habitats, species, communities, and ecological processes to multiple spatial scales and storms; it can

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be defined as the grade in that the landscape facilitates or impedes the movement among patches of resources (Noss 1990).

The objective of this chapter is to offer a panoramic on routes and factors of dispersion phytophagous of natural enemies of pest insects in agroecosystems, as a base for pest management programs.

## 5.2 Dispersion Routes

The dispersion of populations of natural enemies can occur for three main routes: biotic, abiotic, and anthropogenic as well as their combinations. The complexity of the interactions of natural enemies with their cultivations and other host plants and the characteristics of the agroecosystems constitute decisive factors in the necessity and success of the dispersion.

Pathogens can be dispersed in several ways: active discharge of infective spores (local dispersal), weather factors (wind and rain), or by host and non-host dispersal (long-distance dispersal) (Fuxa and Tanada 1987). The transmission of a fungal pathogen is dependent on a number of processes: conidia production, discharge, dispersal, survival, and germination (Hajek and Leger 1994). The large number of conidia produced by infected cadavers partially compensates for the high probability and that many conidia will not actually infect a host (Shimazu and Soper 1986). Indeed, the density and distribution of a pathogen population is one of the most important factors determining whether a disease becomes epizootic (Carruthers et al. 1991).

In an unmanaged host/pathogen system, epizootics are usually host-density dependent, developing as the host population increases. However, an epizootic may develop at low host densities if the pathogen is widely distributed within the host habitat. Pathogen populations are often distributed at low densities or discontinuously in the host habitat and, therefore, pathogen dispersal is essential (Fuxa and Tanada 1987).

Most pathogens have a limited capacity for active dispersal; however, entomophthoralean fungi (except *Massospora*) produce conidiophores that forcibly discharge primary conidia across the leaf boundary layer (Steinkraus et al. 1996).

Dispersal of conidia over a greater distance requires physical factors such as rain and wind or dispersal by hosts and non-hosts. Rain can remove pathogens in splash droplets or by vibration caused by the impact of raindrops. Many studies have shown the importance of rain in the dispersal of plant pathogens (Pedersen et al. 1994), though this may be less important for some entomopathogens such as *Pandora neoaphidis* (= *Erynia*) (Remaudière & Hennebert) (Pell et al. 1997).

Wind is undoubtedly important in the long-distance dispersal of many fungal entomopathogens (Steinkraus et al. 1996) with most fungal conidia being small. However, the dispersion of entomopathogens by weather factors is random in contrast to dispersal by hosts and non-host vectors, which are targeted.

Schellhorn et al. (2014) affirmed that insects use two mechanisms for entomophagous dispersion: auto-directed movements (to walk, to jump, to fall, and to fly) and passive movements (wind, foris, and transport mediated for human). Among the passive movements, wind is considered a factor that influences the air dispersion of parasitoids (McManus 1988; Kristensen et al. 2013). The parasitoids dispersion is influenced by biotic and abiotic factors such as the size of the insect, the gender and state of mating of the parasitoid (Liu et al. 2015), the density of the host (Petit et al. 2008), the direction and speed of the wind (Kristensen et al. 2013), and the presence of chemical signs (Liu et al. 2015).

The insects pass a long part of their time moving among places that offer different resources such as food, refuge, couple, and hosts; this is fundamental for most of organisms and necessary for their survival (Schellhorn et al. 2014). The result of the process of parasitoids dispersion is the encounter and acceptance of hosts (Rehman and Powell 2010). Some insects can control the direction and the flight speed by combining active and passive mechanisms when entering, remaining, and leaving the current of the wind above the canopy (Schellhorn et al. 2014).

Studies carried out by Hernández and Manzano (2016) on the parasitoid *Amitus fuscipennis* MacGown & Nebeker (Platygastridae), a promissory biological control of the *Trialeurodes vaporariorum* (Westwood) (Aleyrodidae), showed that the parasitoid was dispersed up to 12 m and it was the biggest rate that happened in the east direction (15.08%), which suggested that the wind contributes to the passive dispersion once the insect begins the flight. *Amitus fuscipennis* measures less than 1 mm, which helps its passive initial wind dispersion (Hernández and Manzano 2016), as it has been reported for the micro wasps *Trichogramma* (Trichogrammatidae) that cannot fly up against the wind (Keller et al. 1985). On the contrary, a bigger parasitoid, *Gonatocerus ashmeadi* Girault (Mymaridae), with a longitude of the posterior tibia <0.7 mm is not affected by the wind in its dispersion pattern (Petit et al. 2008).

Winds, including those of tropical hurricanes, can directly or in organs of their host plants disperse populations of insects pests and their natural enemies. Two citrus pests and their natural enemies favored by the winds of hurricanes were introduced in Cuba: the citrus leaf miner (*Phyllocnistis citrella* Stainton) (Gracillariidae) with the parasitoid *Ageniaspis citricola* Logvinovskaya (Encyrtidae) (Vázquez and Pérez 1997) and the citrus psilid, *Diaphorina citri* Kuwayama (Liviidae) with *Tamarixia radiata* (Waterston) (Eulophidae) (Vázquez et al. 2009).

Parasitoids and predators of herbivores have evolved and they function within a multitrophic context. Consequently, their physiology and behavior are influenced by elements from other trophic levels such as their herbivore victim (second trophic level) and its plant food (first trophic level). Natural enemies base their foraging decisions on information from these different trophic levels, and chemical information plays an important role. The importance of infochemicals, a subcategory of semiochemicals, in foraging by parasitoids and predators has been well documented (Vet and Dicke 1992).

In a study of larval movement by using video techniques, Furlong and Pell (1996) determined that larvae foraged on by *Diadegma semiclausum* (Hellen) (Ichneumonidae) moved significantly further and into significantly more new areas

of leaf than control larvae. Interestingly, larvae foraged on by a different parasitoid, *Cotesia plutellae* (Kurdjumov) (Braconidae), were intermediate in their movement and were not more likely to become infected by the entomopathogen *Zoopthora radicans* (Brefeld) Batkothan control larvae. This suggests that there is a threshold of movement necessary for the fungal transmission to be encouraged and that this threshold was exceeded by larvae foraged on by *D. semiclausum* but not by *C. plutellae* larvae foraged. These interactions are complex and difficult to predict because they vary between natural enemies. In a similar study, the transmission of *P. neoaphidis* was increased in the presence of the parasitoid *Aphidius rhopalosiphide* Stefani-Perez (Braconidae) (Fuentes-Contreras et al. 1998).

Intraguild interactions are common among communities of biological control agents including interactions between parasitoids and entomopathogenic fungi (Rashki et al. 2009). Mohammed and Hatcher (2017) showed that combining *Aphidius colemani* Viereck (Braconidae) and *Lecanicillium muscarium* R. Zare & W. Gams (Mycotal®) to control *Myzus persicae* Sulzer (Aphididae) may be feasible for controlling the aphid in greenhouse situation as a result of environmental conditions, especially the temperature that favors fungal growth, which can be controlled and also parasitoids can be kept in. A more detailed knowledge of the effects of naturally occurring parasitoids on pest control and their interaction with other biological control agents will help to develop environmentally sound crop management strategies with reduced insecticide applications.

The release of predatory mites accompanied by spray applications of *Beauveria bassiana* (Bals.-Criv.) Vuill. may be a viable alternative in the management of *Tetranychus urticae* Koch (Tetranychidae) populations and possibly improve efficiencies in controlling *T. urticae* (Chandler et al. 2005). The potted plant investigations realized by Shengyong et al. (2018) indicated that *Phytoseiulus persimilis* Athias-Henriot (Phytoseiidae) showed significant aversion behavior to the initial fungal spray but gradually dispersed over the entire bean plants. The study suggests that fungal spray did not affect the predation capability of *P. persimilis* and poses a negligible risk to their behavior.

### 5.3 Dispersion Factors

Getting natural enemies to disperse and multiply in the environment where they are released is one of the greatest challenges of applied biological control. All elements that influence the establishment of these organisms ought to be predicted and avoided for the success of any biological control program. These elements are mainly related to three factors: climatic conditions during the release of the controlling agents, crop characteristics (e.g., architecture and plant age), and attributes that are intrinsic to the natural enemy, such as development stage, biology, and ecology. The study of these factors can provide information on the best technique to be applied and in the calculation of the number of specimens, release points, and the frequency and interval between releases.

**Climate Influence** Most of the natural enemies used in biological control programs (mites and insects) are ectothermic animals. These animals depend on the heat of the environment to activate their metabolism. Thus, a release above or below their optimum temperature can affect the survival and dispersion of these natural enemies in the field. Rain is also a very important climatic factor. Natural enemies in the egg and pupal stages can be washed away by rain and die on the ground before their emergence. The release of *Trichogramma* sp. (Trichogrammatidae) in the rainy season together with the predatory activity of their natural enemies eliminated nearly 80% of parasitized eggs (Smith 1994).

**Crop Characteristics** The architecture and the age of the plants can directly influence the dispersion and persistence of the natural enemies in the field. Characteristics such as leaf width and length, branching, presence of flowers, and structures on the leaf surface (e.g., trichomes) can modify the microclimate as well as food sources and shelter under adverse environmental conditions. *Trichogramma pretiosum* Riley (Trichogrammatidae) was less dispersed in a 90-day tomato crop when compared with the same culture at younger ages (Pratissoli et al. 2005). Larger leaf area, size, and thickness of older tomatoes caused variations in the microclimate and interfered on the search capacity of the parasitoid.

The presence of flowers in cultivated plants might increase populations of natural enemies such as syphidians, coccinellids, chrysopedes, and parasitoids. Parasitoids are mainly used in monoculture systems that present a poor environment during most of the phenological cycle, negatively affecting their dispersion and population increase. The lower availability of floral nectar reduces the search activity by the host and favors the migration to other food-rich areas. Adequate feeding of adults causes several benefits such as increased reproduction and better egg maturation.

**Natural Enemy Characteristics** Biological characteristics such as fecundity, fertility, longevity, and sexual ratio contribute to the reproductive capacity of the natural enemy and, consequently, to its effectiveness in biological control programs. The evaluation of these characteristics in laboratory studies can provide information on their ability to survive and multiply in field conditions.

The age and stage of development of the natural enemy is very important. However, studies are needed to verify the age or stage that provides greater dispersion and survival of these enemies in the field. For example, the stage and the best age for release of *Cotesia flavipes* (Cameron) (Braconidae) are adults with up to 24 hours due to lower mortality rates (Oliveira et al. 2012). Host specificity can also influence the establishment, dispersion, and effectiveness of natural enemies. Predators use more than one individual to complete their life cycle. However, the vast majority are generalists and end up preying on non-target prey. Although parasitoids use only one individual per cycle, they are usually more specialists, converging their parasitism in the target pest. Strains of the same species of parasitoid present differences in relation to host preference, plant recognition and acceptance, search behavior, and tolerance to environmental conditions. Differences in the parasitism rate of different strains of *T. pretiosum* were observed in the control of *Chrysodeixis includens* (Walker) (Noctuidae) (Bueno et al. 2009).

## 5.4 Dispersion of Entomopathogens by Their Phytophages and Other Hosts

The development of a low-cost autodissemination technique for entomopathogenic fungi where the insect can spread the fungus via horizontal transmission to conspecifics (e.g., during mating) is necessary (Avery et al. 2009). Similar autodissemination techniques for controlling pests have been evaluated in other systems (Tsutsumi et al. 2003; Scholte et al. 2004).

Based on laboratory studies, Avery et al. (2009) proposed the potentiality of the autodissemination of *Isaria fumosorosea* Wize is inoculating yellow cards with the entomopathogenic fungus to the Asian citrus psyllid (*D. citri*) as a disseminate technique for managing the pest populations.

Dispersal flight, a well-known strategy for aphids to locate suitable plants, was studied by Feng et al. (2007) for its possible role in disseminating fungal pathogens and parasitoids as natural control agents of aphids by air captures in Hangzhou, China, during 2001–2005. Up to 3183 migratory-winged forms of the green peach aphid *M. persicae* were captured from air using a yellow-plus-plant trap on the top platform of a six-storey building in an urbanized area and individually reared in a laboratory for  $\geq 7$  days. Among the captured winged, 28.9% survived on average for 2.5 days and then died from mycoses attributed to 10 species of obligate or non-obligate aphid pathogens. These were predominated by *P. neoaphidis*, which caused 80% of the winged mycoses. Another 4.4% survived for an average of 3.7 days, followed by mummification by *Aphidius gifuensis* Ashmead (Braconidae) (52.9%) and *Diaeretiella rapae* (M'Intosh) (Braconidae) (47.1%).

An autoinoculative device was used to test the ability of sap beetles (Nitidulidae) to carry a specific strain of *B. bassiana* to overwintering sites in a multiyear field study. The device was baited with the pheromone and coactrants for the dusky sap beetle (*Carpophilus lugubris* Murray) and placed in the field in the fall of each year. The autoinoculating device provides selective contamination of sap beetles in overwintering sites when used in the fall. It may be useful in providing some control of sap beetles or other insects where limited numbers of mass overwintering sites (such as tree holes) occur (Down and Vega 2003).

Studies carried out by Gross et al. (1994) suggested that *Apis mellifera* L. (Apidae) can disseminate insect pathogens be applicable for pest control will depend on an improved understanding of the interrelationships among *A. mellifera*, flowering plants on which they forage, targeted phytophages that reside on the plants, and the availability of pathogens that attack the phytophages. The mean percentage of HNPV-induced mortality was significantly higher among *Helicoverpa zea* (Boddie) (Noctuidae) larvae that fed on clover heads from fields foraged by HNPV-contaminated *A. mellifera* and among *Helicoverpa* spp. larvae collected from those fields than among similarly exposed control larvae.

Pollen beetles, *Meligethes aeneus* Fabricius (Nitidulidae), are pests that feed and oviposit in the buds and flowers of oilseed rape. Honeybees foraging from a hive fitted with an inoculum dispenser at the entrance effectively delivered dry conidia of the entomogenous fungus, *Metarhizium anisopliae* (Metchnikoff) Sorokin to the

flowers of oilseed rape in caged field plots. Mortality (61% on winter rape, 100% on spring rape) was higher during peak flowering, when the feeding activity of both bees and beetles from the flowers was maximal, providing optimal conditions for inoculum dissemination and infection. Conidial sporulation occurred on a significant proportion of the dead pollen beetles. There was no evidence of any adverse effect on the honeybee colonies (Butt et al. 2010).

## 5.5 Dispersion of Entomopathogens by Entomophagous

It has long been recognized that predators and parasitoids contribute to the dissemination of viral entomopathogens and the development of epizootics. However, only a few more recent studies have assessed the transmission of fungal entomopathogens by non-host vectors (Butt et al. 2010).

The presence of insect natural enemies may have an impact on local transmission of a fungal pathogen. The presence of a foraging adult coccinellid, for example, resulted in a substantial increase in the local transmission of the aphid pathogen *P. neoaphidis* within a population of pea aphids, *Acyrtosiphon pisum* Harris (Aphididae) on individual bean plants in the laboratory (Roy et al. 1998). Foraging ladybirds cause an increase in aphid movement, although the degree to which this occurs depends on the aphid species and host plant (Hajek and Dahlsten 1987). The increase in movement of aphids in the presence of foraging predators such as coccinellids would increase the probability of the aphid coming into contact with the sporulating cadaver, and therefore receiving more inoculum.

In laboratory conditions, studies carried out by Meyling et al. (2006) revealed that the aphid *Microlophium carnosum* Buckton (Aphididae) and its predator *Anthocoris nemorum* (L.) (Anthocoridae) dispersed conidia of *B. bassiana* from the soil toward the cultivation and from cadavers in the foliage of the plant.

A good example of natural autodispersion happens in the interaction between the coffee berry borer, *Hypothenemus hampei* (Ferrari) (Curculionidae) and *B. bassiana* in coffee plantations. According to Bustillo (2006), among the entomopathogenic fungi that naturally regulate the populations of this pest in Colombia, *B. bassiana* is the one that is observed in almost all the regions where this insect appears. Similarly, Vázquez et al. (2010) informed that in Cuba the epizootics caused by this fungus happened between 21 and 98 months after the detection of the pest in the different territories. A cadaver of *H. hampei* well sporuled with *B. bassiana* is able to produce about ten million spores that can be dispersed by a natural way to establish in the coffee plantations (Narváez et al. 1997). It is considered that approximately 49% of total coffee berry borer population in a coffee plantation dies as consequence of the regulatory activity of *B. bassiana* (Ruiz 1996).

A very interesting case was studied by Forschler and Young (1993), in Arkansas, USA, who observed adults of *Diabrotica undecimpunctata* Howardi (Chrysomelidae) to feed on cadavers of *H. zea* killed by *H. zea* nuclear polyhedrosis virus. Laboratory bioassays showed that excreta from adults of *D. undecimpunctata* fed on virus-killed



cadavers collected up to 3 days after feeding resulted in virus mortality of *H. zea*.

## 5.6 Anthropogenic Dispersion

The releases and applications of entomophagous and entomopathogenic that are carried out for the pest population control be inundative or inoculative constitute the main route of anthropogenic dispersion of the biological control agents. Many techniques have been developed and are applied in the agricultural production with this purpose and for the dispersion of natural enemies that inhabit the agroecosystems.

**Capture-Inoculation Trap with Entomopathogenic Releases** Pozo et al. (2006) found that scarabs of the genera *Phyllophaga* and *Cyclocephala* (Scarabaeidae) that attack the cultivation of the pineapple, *Ananas comosus* (L.) Merrill, were captured by a system of traps that combines the attraction of adults to the light and their collection in a tray that contains a suspension in water of entomopathogenic nematode, in a dose of  $3 \times 10^6$  juvenile for trays of  $50 \times 50$  and a million for trays of  $25 \times 25$  cm. The captured adults were infected with the juvenile of the nematode, which were transferred by the adults that escaped from the trap and disperse them toward the system radicular of the cultivation where they inhabit larvae of the pest.

Pozo (2013) referred an effectiveness of 74% in the biological control of *Cosmopolites sordidus* (Germar) (Curculionidae) and *Metamasius hemipterus sericeus* (Olivier) (Curculionidae) in banana plantation by using traps elaborated with pseudo stem of bananas cut as sandwich, where a suspension with entomopathogenic nematode was sprayed using a dose of 3000 immature juvenile of instar 3/ trap.

**Direct Collect-Artisanal Rearing-Released** Another way of dispersion is the breeding of the natural enemy in its own agroecosystem to later disperse it in different places. In Cuba, Castiñeiras et al. (1982) created and introduced a methodology to collect and multiply the ant *Pheidole megacephala* (Fabricius) (Formicidae) by means of artificial reservoirs. From these reservoirs, workers and reign populations were moved to inoculate the colonies in recently planted fields of the cultivation of the sweet potato, *Ipomoea batatas* (L.) Lam. (Convolvulaceae), with the purpose of controlling populations of the sweet potato weevil, *Cylas formicarius* (Fabricius) (Brentidae). Castiñeiras and Ponce (1991) found that by placing nine colonies of ants/ha against sweet potato, there was a 22% damage reduction and 68% of the population of adult pests reduction.

A similar procedure was proposed by Roche and Abreu (1983) by developing artificial reservoirs of the ant *Tetramorium bicarinatum* (Nylander) (Formicidae) to transfer and inoculate colonies in banana fields (*Musa* spp.) that are infested with banana black weevil (*C. sordidus*), which is also a pest of importance in this cultivation. According to Bendicho and Gonzalez (1986), *T. bicarinatum* was able to control approximately 65% of the total population of the pest in fields with high infestation and that in low populations it elevated the control percentage



until 83.5%.

**Direct Collect-Transfer** Social insects can be manipulated by the farmer with the objective of increasing their populations to regulate pest. Wasps from the genus *Polistes* are important biological control agents and stand out as predators of agricultural pests, especially caterpillars. Their colonies are easily manipulated and transported to artificial shelters because of the small nests with peduncle. This practice was carried out in Colombia, where the farmers made shelters to the wasps *Polistes* to make their nests; later these shelters are transferred to the fields of cultivations with more necessity (García 2000).

Colonies of social wasps are best sampled early in the evening, which should be carefully performed so the peduncle is not destroyed. After capture, the colonies are placed in the desired environment using cyanoacrylate ester-based glue. Wooden board shelters (15 × 20 × 1 cm) in the form of a roof are attached to a 1.8-m support (Prezoto and Machado 1999) (Fig. 5.1). Burned oil and grease are applied to the base of the support to prevent ant attacks. The wood structure can be replaced by plastic containers, which facilitate the translocation of the shelters (Elisei et al. 2012) (Fig. 5.2). Four colonies of *P. simillimus* arranged on each side of an experimental plot cultivated with corn (10 × 10 m) at a distance of 2 m from the crop limit caused a reduction of 77.2% in the occurrence of *S. frugiperda* when compared to areas without the presence of wasp colonies.

A single technique of natural enemies dispersion is practiced by farmers, which consist in collecting leaves with populations of pests, which are parasited for entomopathogenic fungus and transfer them to fields or parts of them where has not shown the epizooty (Vázquez and Elósegui 2011).

Experiences have also been documented in agroecosystems of Cuba on the collection and transfer of small populations of entomophagous, such as adults of the *Zelus longipes* L. (Reduviidae), nymphs and adults of *Orius insidiosus* (Say) (Anthocoridae), larvae and adults of Coccinellidae, eggs and larvae of Chrysopidae, and larvae of lepidoptera infected for entomopathogenic virus. Cases of entomophagous transfer have been systematized from experiences of farmers (Caballero et al. 2003; Vázquez et al. 2008). For example, eggs of lepidopterous parasited *Trichogramma* and *Telenomus*, leaves with mines of leafminer parasited (Agromyzidae); leaves with colonies of aphids parasited *Lysiphlebus testaceipes* (Cresson) (Braconidae); leaves with colonies of whiteflies parasited *Encarsia* and *Eretmocerus*; leaves and branches of coffee with colonies of *Coccusviridis* (Green) (Coccidae) parasited *Lecanicillium lecanii* R. Zare & W. Gams; leaves with colonies of aphids parasited *Entomophthora*; leaves with colonies of whiteflies parasited *Aschersonia*; leaves with larvae of *Spodoptera* parasited *Euplectrus*; cottons of *Apanteles* in cassava, leaves with eggs of *Pachnaeuslitus* (Germar) (Curculionidae) in citrus parasited *Tetrastichus*; leaves with colonies of predators acari; and fruits of coffee infested by *H. hampei* parasited *B. bassiana*.



**Fig. 5.1** Shelter for translocation of social wasp colonies: (a) wooden support of 1.80 m; (b) social wasp colony shelter. (Photo: Gabriel C. Jacques)

**Fig. 5.2** *Polistes versicolor* colony translocated to an artificial shelter. (Photo: Gabriel C. Jacques)



## 5.7 Final Remarks

The cluster previously used for different ways of natural enemy dispersions does not seek to establish a system to classify them, but it is rather carried out to contribute to the understanding of the diversity of these processes and their practical importance. It was not sought to drain the topic because the available information is wide. Nevertheless, there is a need for demand of basic and applied investigation to integrate practical of natural enemy dispersion in pest management.

The complexity of the designs of systems of mixed cultivations (polycultures, polyfruits, others) and the integration of auxiliary vegetation structures (ecological corridors, alive barriers, among others) in the matrix of the production systems, among other practices of biological control for conservation, are facilitating the dispersion of natural enemies.

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