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The use of biocidal products to control urban pests and vector arthropods

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Abstract

Pest management and vector control are important for their impact on health, quality of life, and the economy of touristic areas. The many different methods with which insecticides are applied, the specific equipment required, and the lack of clear terms often give rise to confusion and misunderstandings. This paper organises and describes their application methods, equipment, and most suitable use, and highlights their strengths and weaknesses.

Keywords

insecticide application methods – droplet – pest control – vector control

1 Introduction

Insects, together with other classes of arthropods, include many species of great interest for the medical and veterinary health and the hygienic sanitation fields. They play a crucial role as potential mechanical and/or biological vectors of pathogens that can be transmitted to humans directly or indirectly (e.g. surface contamination), or as agents of dermatological and/or allergic reactions (Becker *et al.*, 2003; Taylor *et al.*, 2010).

In addition to eliciting purely medical and veterinary interest, some groups of insects, such as mosquitoes, can reduce the quality of life of people living in areas infested by them (Halasa *et al.,* 2014). This problem has recently been made worse, in European countries, with the relatively recent introduction of *Aedes* (*Stegomyia*) *albopictus* (Skuse, 1894) (Romi, 2001).

Management of arthropod vectors is a key element in governmental plans to control the spread of vector-borne diseases (VBDs) (Bellini *et al.,* 2011; WHO and EMCA, 2013). In addition, pest control is a minimum standard in the food chain (Marriott and Gravani, 2008).

Control methods can be divided into direct – aimed at eliminating infestation – and indirect – aimed at avoiding or limiting the creation of favourable conditions for infestation – and are commonly defined as prevention measures. At times, the difference between the two is minimal. Although turning a bucket upside down is an indirect method used to prevent mosquito breeding sites, if the bucket is already filled with water where larvae are present, then the action of emptying can be considered a direct method. Direct methods include techniques that can be divided into the following actions: mechanical (e.g. mass trapping), physical (e.g. high or low temperatures), chemical (e.g. toxic molecules) and biological (e.g. predators) (Lorenzini and Nali, 2012; Stejskal *et al.,* 2021). Biological methods also include the use of bacterial toxins, bacteria, and insects treated to make them sterile (irradiation infertility) or unable to produce fertile eggs (Wolbachia) (Alphey *et al.*, 2010; Bellini and Corazza, 2000; Bouyer *et al.*, 2020; Carrieri and Bellini, 2000).

Legislative methods is another category and consists in the emanation of rules or laws specifically aimed at

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fighting pests. Such rules can be implemented as prevention strategies to thwart the introduction of invasive species (e.g. fumigation of shipping containers, ban on the importation of used tyres from countries where the Tiger mosquitoes are present, quarantine for imported lucky bamboo). Moreover, specific local rules may limit the spread of an invasive species already found in the area, hinder the proliferation of a pest or focusing on its elimination (e.g. making it mandatory to keep tyres covered, or to apply larvicides in private property, or to eliminate potential breeding sites).

Critical for the effectiveness and efficiency of chemical controls is the choice of active ingredients, their formulation, and their application methods (Rose, 1963; Stejskal *et al.*, 2021). This is also essential in terms of intervention safety, as controls must limit chemical contamination and eco-toxicological effects on the environment, food and non-target species (Bianco, 2015).

Excessive and improper use of biocides in closed environments (e.g. homes, airplanes) can be harmful to human and pet health (Sarwar, 2016; Vanden Driessche *et al.,* 2010), and sometimes requires environmental decontamination interventions (Oudejans *et al.,* 2020). It is important to consider that reduced sunlight penetration in domestic and working environments helps to limit natural degradation factors of molecules like pyrethroids while, at an eco-toxicological level, the use of insecticide formulations in private areas may contaminate watercourses following washout of the treated surfaces (Richards *et al.,* 2016).

Although the most remarkable effects on both human health and the environment are closely associated with the physical-chemical characteristics of the molecule and its dosage, application techniques and equipment play an essential role in mitigating or worsening the toxicological effects of interventions (Pieper *et al.,* 2014).

In agriculture, the application of plant protection products has been analysed extensively (Baldoin, 2012), and aims both at reducing the impact on health and the environment, and at improving the effectiveness of interventions. Unfortunately, the same cannot be said for biocides in urban, rural, and industrial areas, of which the use gives rise to some terminological confusion and potentially incorrect application techniques. While the WHO Guidelines 'Equipment for vector control' (WHO, 2018) focus on mosquito control, our article analyses the application methods used in urban pest and vector controls against several flying and crawling insects viewed as annoying rather than as vectors.

2 Methods of insecticide application

Application methods vary greatly according to active ingredient, formulation, stage of development of the pest and the environment where the insecticide is applied, both in terms of type and size. In this article we decided to classify the application methods by considering the following variants:
– extent of application area;
– volume of solution distributed per unit area;
– size of the distributed particles or droplets.

Classification by extent of the application area

Classification by extent of the application area divides interventions into:

1. Generalised. When applications aim to affect a given area (area treatment) or a given volume completely. In this case, they are also called 'space treatments' or 'spatial treatments' or 'wide area treatments'. When carried out in open environments, they potentially have the greatest eco-toxicological impact on non-target species (Bianco, 2015; WHO, 2018). Deltamethrin, an active ingredient widely used in pest control treatments, has high LD50 contact towards honeybees (*Apis mellifera* L., 1758) equal to 0.0015 μg/bee (PPDB, 2021), and a theoretical environmental toxicity equal to 0.05 $\mu g/cm^2$ (Mestres and Mestres, 1992). Widespread environmental applications select the individuals carrying resistance genes to the insecticide, thus producing resistant populations. Moreover, many cases of insect populations resistant to pyrethroids are reported in the literature (Brengues *et al.,* 2003; Lemine *et al.,* 2018). Widespread space application can also give rise to safety problems due to possible drift phenomena and the creation of a noxious environment.

   With regards to vector control (mosquitoes), drop size must be <30 μm, since the insecticide molecule must be airborne suspended long enough to be intercepted by the target (WHO, 2018). When spatial application is carried out indoors, the term 'saturation' is often used, although it should only refer to gases and their unique ability to penetrate cracks and slits.
2. Localised. Also called 'spot application': when the application takes place in spots, thus concentrating insecticide dispersion in specific areas such as cracks and crevices, manholes, saucers, etc.

This is the safest application for humans and non-target species, both because the diffusion of the solution/formulation may be better controlled, and because it focuses the effect of the product only in the areas affected by the pest, limiting environmental chemical contamination.

3. Barrier/perimeters. When the application is carried out in strips or limited areas of vegetation to hinder or limit the circulation of pests and vectors from an infested area to a non-infested area. Perimeter treatments can also aim at wiping out the pest completely, and barrier applications may be used both indoors and outdoors.

   In order to be effective and therefore justified, outdoor applications for mosquito control must meet the following requirements: (a) the target species must rest in the vegetation before and/or after taking a blood meal, (b) breeding sites must not be located within the barrier, (c) insecticides with long residual times must be used, and (d) adult mosquitoes must be able to come into contact with the insecticide (Perich *et al.,* 1993). Barrier treatments for mosquito control were first used in the mid-1900s (Stoops *et al.,* 2019).

Classification by volume of solution distributed per unit area

The classification based on applied insecticide volume per unit area originates from the agricultural sector (Vieri, 2004), where large homogeneous areas are the norm. Clearly, the smaller the quantity of insecticide solution applied per surface unit, the higher the concentration of active ingredient is needed (Table 1). Since the insecticide has to be applied as homogeneously as possible, when small volumes are applied on large areas, droplet size must be reduced. This is so obvious that terms indicating volumes as synonyms of droplet size have become commonplace. For example, although the term ULV means Ultra Low Volume and refers to the quantity of insecticide solution applied on one hectare, it is commonly used to indicate a droplet size smaller than 30 μm. VLV (Very Low Volume) applications use diluted commercial formulations in small quantities of particular solvents (glycols) for fogging application (FAO, 2001).

Classification by droplet diameter

The application of insecticides may be classified further according to the diameter of the droplets through which the insecticide solution is introduced into the environment. Droplet size is essential, as it influences treatment effectiveness and, together with surface tension, defines different degrees of wetting and safety (the smaller sized droplets float longer in the air and can be easily breathed in).

Currently, the classification of droplet size must be based on volume median diameter (VMD) or numerical median diameter (NDM). The VMD refers to the midpoint droplet size, where half of the volume of spray is in droplets smaller, and half of in droplets larger than the mean. The NMD is the droplet diameter where the number of droplets above the NMD is equal to the number of droplets below the NMD. The ratio between the two provides an indication of uniformity of the droplets produced.

As already discussed in the previous section, although the term ULV elates to the classification by volume of solution distributed per unit area, uniform application of such a small quantity of product necessarily implies the use of equipment that generates very small droplets which persist in airborne suspension. This characteristic is both positive, as it provides longer efficacy and

TABLE 1 Classification of biocide application based on unit volume per unit area.

Classification volume	Litres per 100 m² of surface treatments (two-dimensional treatments)	Litres per 100 m² of space treatments (three-dimensional treatments)
High (HV)	>6	>10
Medium (MV)	2–6	5–10
Low (LV)	0.5–2	2–5
Very low (VLV)	0.05–0.5	0.5–2
Ultra low (ULV)	<0.05	<0.5

better penetration into the vegetation, and negative, as the droplets drift easily and cannot be controlled. In the context of vector control, when the ULV technique is used, average droplet diameter is preferably between 5 and 25 µm (Stoops *et al.*, 2019).

Classification of applications based on droplet size is one of the most confusing in the literature. Several authors provide different interpretations and use different terms or use the same term but refer to different sizes (Hoffmann *et al.*, 2008; Matthews and Bateman, 2004; Nengle *et al.,* 2023; Potts, 1959; Romi, 1997; Vieri, 2004; WHO, 2018). The use of the same terms but related to different sizes in the classification of both spray nozzles (Nengle *et al.*, 2023) (Table 2) and droplet size (Table 3) generates confusion. From a safety viewpoint (i.e. to minimise drift), droplet size selection has to take into consideration the time it takes a droplet to reach the ground (Table 4). It is important to consider that droplets with a diameter <150 µm move downwind of the point of release, and this is fundamental for the evaluation of effects due to drift (FAO, 2001). Consequently, applications of smaller droplets should be preferred in closed environments, while application systems that generate larger droplets are preferable outdoors. Droplet size for barrier treatments on vegetation must avoid rapid fallout, and an average diameter of 50–100 µm is therefore preferable (WHO, 2018). Such droplet size, together with the high quantity of insecticidal solution applied, enables vegetation wetting, and ensures prolonged efficacy when residual insecticides are used. Due to the waxy protective film found on many plant species, insecticidal solutions cannot simply wet the vegetation, as they would run off. Products may be added to insecticides to reduce surface tension. If the treatment is targeting mosquito larvae (e.g. in ponds, canals, ditches), droplet size must prevent any drift, and the VMD should not be less than 200 µm. Occasionally, breeding sites can be very small and difficult to reach (e.g. in tyre piles or other materials containing rainwater). In these cases, misting machines for the application of larvicides yield better outcomes (Jacups *et al.,* 2013; William *et al.,* 2014).

TABLE 2 Classification of spray nozzles, according to Nangle *et al.* (2023).

Volume median diameter range (µm)	Spray quality
> 665	Ultra coarse
503–665	Extremely coarse
404–502	Very coarse
341–403	Coarse
236–340	Medium
106–235	Fine
61–105	Very fine
<61	Extremely fine

TABLE 4 Minimum droplets falling time, adapted from Tremblay (1999) and Potts (1959).

Diameter of droplets (µm)	Falling time	
	Fall from 1.5 m in still air	Fall from 15.24 m in still air
1	–	5 days
5	30 min	5.5 h
10	10 min	1.4 h
20	–	21 min
40	–	5.2 min
50	20 s	3.4 min
80	–	1.3 min
100	5 s	51.0 s
200	–	13.0 s

TABLE 3 Classification and types of application based on droplet size.

Type of application		VMD (µm)	Field of use[1]
Spray	Coarse	> 400	Larvicidal (VMD 150–500 µm) Internal Residual Spray (VMD 120–200 µm)
	Medium	>250–400	–
	Fine	>100–250	–
	Fine mist	50–100	Barrier treatment (VMD 50–100 µm)
Fog/Aerosol		0.5–50	Cold and thermal fog (space treatment)
Aerosol		0.1–1	–

[1]The fields of use are recommended by WHO (2018). VMD = Volume median diameter.

The solid, liquid or gaseous substances that are toxic to arthropods after transitioning to a gaseous state (toxic or fumigant gases) are yet to be described. These types of products, which include methyl bromide and phosphine, are generally applied to disinfest food and wood in storage sites (warehouses) (Gelosi, 1989), and their use is increasingly limited due to their significant environmental impact and their acute, chronic toxicity (Budnik *et al.,* 2012; Yates *et al.*, 2003).

The application of solid formulations

Insecticides may also be applied through solid carriers. The active ingredient in these types of products is associated, through mixing or absorption, with an inert mineral/organic compound and distributed with different grain sizes. In the case of baits an attractive food component can be added. Solid formulations include:

- Fine powders; diameter ±40 µm. These products are typically formulated in dispensing packages or may be distributed through manual sprayers;
- Microgranules; diameter 100–600 µm;
- Granules; diameter >600 µm. They are typically formulated in dispensing packages.

The use of fine powders should be restricted to enclosed spaces as micro-dusts can blend with environmental dust and be easily inhaled when relative humidity is low.

3 Equipment for the application of biocidal solutions

In the field of pest control, the equipment used for the different types of applications comprises the following:

- Dispensers. Plastic or metal devices associated or not with electronic or mechanical timers that allow the products to be released in solid formulation. Dosing devices may use motorised vehicles (e.g. scooters for the treatment of road drains) and remotely piloted aircraft (APR) also called 'drones'. As for APR, the laws concerning their use in pest and vector control (flight license, limitations in their use) are not clear yet, and may differ from country to country.
- Self-draining sprays and fumers. Self-draining sprays are a range of products widely used in the DIY sector because they distribute formulations easily and do not require further preparations/dosages. In general, they are pressurised cans containing an insecticide mixture in association with an inert propellant gas which determines their automatic release favoured by a device blocking the dispenser. Fumers are products in which the active ingredient is absorbed on slow-burning material and is released into the environment gradually through combustion. Other methods include hydro-reactive flameless fumers which eliminate any fire risk and are therefore safer. Furthermore, the absence of combustion prevents the release of burnt material, leaving the environment free of unwanted residues. When using self-draining devices under pressure, the insecticide solution mixture is airborne suspended while the product disperses into the air. They usually generate an aerosol-mist with droplet sizes between 1 and 100 µm and are recommended for the treatment of small spaces. In terms of safety and effectiveness, the drawbacks of these devices are the difficulties in controlling the dispersion of the insecticide 'cloud' and their limited effectiveness against crawling insects, due to the poor or zero penetrating capacity of the insecticide fallout. As regards devices that exploit combustion (fumers), attention should be drawn to the toxicological aspects of combustion products, such as the potential emission of particulate matter and formaldehyde (Chen *et al.,* 2008; Liu *et al.,* 2003).
- Thermo foggers. The concentrated insecticide formulation is dissolved in a solvent such as naphtha, glycol or petroleum that is pumped, into a chamber heated to a temperature which evaporates the solution. Sometimes the solvent may simply be water, although the resulting fog is less dense and persistent. The fog generally spreads by thermal gradient or through fan-generated air flow. The average diameter of the droplets generated is <30 µm. These devices have a high ecological impact due to the column of fog they create, which can remain suspended hours in closed environments. Thermo-fogging therefore is very effective at penetrating pipes, cracks and cavities, and so useful in treating shipping containers and sewers. However, this method is unsuited for use in an external environment as the uncontrolled drift determines has a substantial negative environmental. Thermal fogging also give rise to critical safety issues associated with the use of flammable liquids and the impossibility of controlling the direction of the drift especially in outdoor uses (Dutto and Rubbiani, 2011).
- Pulverisers. Portable tools (bellows), generally operated manually or by an electric motor, which apply dry powders through air flow. They can be equipped with special jet extensions to direct the powder formulation inside cracks or fissures, for example, for bed bug control (Singh *et al.,* 2016) or inside rodent burrows (Parshad and Malhi, 1995).
- Syringes. Plastic or steel tools of simple construction with a piston or trigger used for the environmental application of gel formulations. Syringes can either

dispense, or dispense – dose. In the latter case, a constant dose of formulation is dispensed each time the trigger is pressed. In general, dosage is determined by the diameter of the droplet; manufacturers indicate the mg of formulation dispensed with each single droplet or with each metering click of the tool. These devices are used to control cockroaches and ants as they enable localised treatments and thus, if used correctly, limit the degree of environmental chemical contamination considerably.
- Sprayers. Equipment that comes in various shapes, generally made up of a main tank containing the mixture to be distributed and a hydraulic circuit to draw the liquid from the tank and carry it, possibly increasing its pressure, towards the atomiser.

Insecticide solutions may be atomised in two ways (Bodria *et al.,* 2013):
- Mechanically (airless atomisation): a pump keeps the liquid under pressure in a hydraulic circuit and pushes it through the nozzle, which generates droplets of various sizes depending on the nozzle.
- Pneumatically (air-assisted atomisation): the liquid is sent through a low-pressure hydraulic circuit (0.5–2 bar) to pneumatic diffusers (in place of nozzles) in a variable section duct (Venturi tube) where a high-velocity air jet, generated by a centrifugal fan, pulverises and transports droplets to the target area (Bodria *et al.,* 2013).

Pesticide-spraying equipment can be grouped according to its spraying system:
- Hydraulic sprayers. Equipment that may be portable and equipped with motor-driven (electric or petrol) or manually operated pumps with 2–25 l tanks (backpack sprayers or knapsacks, hand pump sprayers) even up to 50–120 l (sprayer wheelbarrows, motor pumps), or mounted on vehicles and equipped with petrol engine pumps (sprayer lances). Droplets are projected at varying distances, normally <5 m, based on the amount of kinetic energy given by the hydraulic system. They are best suited for the treatment of restricted areas, even closed ones. Although droplet size in carried or projected jet sprayers depends on the type of nozzle (hole Ø) and the operating pressure, these sprayers usually generate droplets between 100 and >600 µm in size (Baldoin, 2012). Equipment with the same operating mechanism can also be air transported by helicopters, hang gliders or airplanes. Flight height, forward speed and width of the treated strip depends on the vehicle and the operational conditions (windiness, vegetation). The aircraft usually have a treatment autonomy of 8–10 ha. Treatment with aerial means is indicated for large areas and in well-detailed cases (e.g. health emergencies) due to its high environmental impact.
- Atomisers. Vehicle-mounted, 200–300 l tank equipment whose nozzles generate droplets carried by an air current (20–50 m/s) produced by an axial fan (6,000–8,0000 m^3/h). This type of equipment is recommended for volumetric treatments of large areas and outdoors; indoors they may be used on farms during sanitary break or in industrial settings. Droplet size in carried or self-propelled jet sprayers is given by the type of nozzle (hole Ø) and the operating pressure. These sprayers generally produce droplets between 100–600 µm in size with airless atomisation systems and 50–100 µm with air-assisted atomisation (Baldoin, 2012).
- Hydraulic sprayers and atomisers are suitable for MV and HV (see Table 1). Standard ANSI/ASABE S572.1 defines droplet spectrum categories for the classification of spray nozzles (Table 2).
- Rotary atomisers. Special equipment in which droplet size is determined by centrifugal reaction. This equipment can be mounted on aircraft or terrestrial vehicles. Droplets generally have a diameter ranging between 10 and 90 µm (Clayton *et al.*, 2002). The use of aircraft to control major vector-borne disease outbreaks through the selective application of pesticides continues to play a critical role in preventing the spread of disease in many parts of the world. Aerial applications allow health authorities to treat large areas rapidly and reduce the presence of vectors such as mosquitoes, flies and molluscs that transmit severe human and animal diseases (Clayton *et al.*, 2002). For the efficacy of the aerial treatment, the orientation of the atomiser determines the size of the droplets; for the control of Culicidae and *Glossina* a droplet size of 10–30 µm is indicated, while for the Muscid flies droplets with a diameter of 40–80 µm are indicated (Clayton *et al.,* 2002).
- Nebulisers. Nebulisers are used for LV, VLV and ULV (see Table 1) applications, and can be portable or vehicle-mounted. Motorised knapsack mist blowers have tanks of about 15–20 l, while vehicle-mounted equipment has tanks of several hundred litres. In vector control, knapsacks are used both indoors (e.g. farms, industrial areas, sewers) and outdoors, and produce droplets below 100 µm (Romi, 1997). To meet guideline standards, portable equipment must guarantee a droplet range of 10 m horizontally and at least 6 m vertically (WHO, 2018). Hoffmann *et al.* (2009) analysed several devices and found VMD

varying between 14.8 and 61.9 µm for oily solutions, and between 15.5 and 87.5 µm for aqueous solutions. ULV systems are considered effective in controlling mosquitoes if droplet diameter is approximately 15–20 µm (Curtis *et al.,* 1996; Bonds, 2012) while too small (7 µm) or too large (26 µm) droplets can compromise the effectiveness of the active ingredient (Curtis *et al.,* 1996). If using ULV indoors – e.g. in cases of arbovirus epidemics – 4 µm-diameter droplets have been found to penetrate the recesses of homes and remain suspended for 2 min post-treatment (Perich *et al.,* 1992).

- Electrostatic sprayers. Sprayers in which droplets are charged positively to make them adhere to the negatively charged vegetation. This technology is very useful in agriculture, both because drift is reduced, and because plants are more uniformly covered. In pest control, it is only suitable in well-defined conditions, like the treatment of vegetation with residual insecticides against species that usually rest on it, like *Aedes albopictus.* The electrostatic droplet charging can be installed on hydraulic sprayers, atomisers, and nebulisers.
- Aerosol projectors (cold foggers). Portable devices equipped with 2–5 l capacity tanks producing 5–50 µm droplets. Some types of equipment use ultrasound micronization and generate droplets about 5 µm in diameter. Dispersion in the environment occurs through air flow.
- Residential misting systems. Fixed misting systems installed in the open spaces of homes (gardens, backyards) for automatic treatments. They are made with an electric pump connected to a tank, which pressurises the insecticide solution (generally pyrethrins or pyrethroids) inside small pipes equipped with micronizing nozzles. The system is generally connected to a timer to adjust the number of sprayings per day (generally between 1 and 3) and their duration. This type of insecticide application is mainly used to control mosquitoes, and its effectiveness varies considerably with the environmental conditions. Cilek *et al* (2008) reported a highly variable reduction of Culicid Diptera from 98 to 14% and showed that the insecticidal effect is achieved by the direct exposure of the target to the active ingredient and not following contact with the treated areas. Although effective when insecticide molecules are used, this type of application must still be investigated in terms of safety, as the degree of environmental chemical contamination is high in peri-domestic environments, where the most sensitive segments of the population (such as children and subjects with underlying pathologies) usually live. Furthermore, insecticide drift can affect other areas where people allergic may be. This application system raises concerns of exposing target insects to frequent sub-lethal doses of insecticide causing insecticide resistance as well as impacting non-target species.

4 Conclusions

In conclusion, it is important to underline that the efficacy and safety of a biocidal treatment relies on the correct choice of the application system, of the formulation in the target environment, and of the most appropriate equipment. These factors need to be evaluated in terms of a risk/benefit ratio. The incorrect use of a biocidal product represents a problem because of its impact on health, particularly in the developing countries where insecticidal products are often used indoors, and the warnings reported on the product label are rarely heeded (Nalwanga and Ssempebwa, 2011; Sarwar, 2016). In addition, misapplication of biocides can promote the development of resistance to active ingredients, as widely observed for mosquitoes (Brengues *et al.,* 2003; Lemine *et al.,* 2018; Stejskal *et al.,* 2021).

From the point of view of operator safety, it is important to underline that all the equipment used in pest control not only has high contamination risks, but is also a fire hazard, especially during thermofogging applications. Non-target animals and the environment in general are also at risk of contamination (Cappelli and Vieri, 1998).

Emphasis should be placed on maintaining the efficiency of application tools/equipment – even in the absence of mandatory provisions – as a requirement that every professional pest control company should meet. The use of equipment in optimal conditions, verified through periodical functional checks and calibrations, guarantees that formulations are dosed correctly. Application methodologies must not only be suitable for the type of pest and the operational environment, but also should always comply with what is indicated on the biocidal product label to ensure adequate levels of efficacy as well as health and environment protection. It is equally important for application techniques and their associated equipment to be clearly and unequivocally indicated in tender specifications, using standard terminology as much as possible, to prevent issues in the performance of the service, which could impact both quality and safety negatively. Table 5 provides a synthesis of the different types of applications, with their strengths and weaknesses.

TABLE 5 Synthesis of the different types of application, the targets, and their positive and negative aspects.

Type of application based on the area size	Type of application based on the droplet size	Target	Positive aspects	Negative aspects
Generalised	Fogging	Flying insects, outdoors	– Good penetration into the vegetation – No residual efficacy (limited contamination of the environment) – Easy to perform – Fast results – Treatment of large surfaces in a short time	– Massive drift – Environment contamination – Low efficacy on good flyer mosquitoes – No residual efficacy (less harmful for non-target organisms) – Medium skilled and experienced workers are required to apply the insecticide in the right places
		Flying insects, indoors	– No residual efficacy (limited contamination of the environment) – All the insects are reached by the insecticide	– No residual efficacy (the treatment must often be repeated) – Need to evacuate the area during treatment
		Crawling insects, indoors	– Flushing effect – Penetration in cracks and crevices	– Limited efficacy for big-sized or tolerant/resistant insects – Medium skilled and experienced workers are required to apply the insecticide in the right places
	Medium fine mist spray	Flying insects, outdoors	– Residual efficacy (with residual insecticides) – Limited drift	– Residual efficacy (greater impact on non-target organisms) – Higher volumes are required – Medium skilled and experienced workers are required to apply the insecticide in the right places
Localised	Coarse mist concentrate spray	Flying and crawling insects, outdoors/ indoors	– Controlled distribution, limited contamination of the environment – Residual efficacy (with residual insecticides) – Simple devices required	– Labour intensive – Possible damage to treated surfaces – High skilled and experienced workers are required to apply the insecticide in the right places
Barrier/ perimeter	Coarse/medium fine mist spray	Flying and crawling insects, outdoors/ indoors	– Controlled distribution – Grade of contamination of the environment between generalised and localised applications – Easy to perform	– When performed against mosquitoes outdoors, it is only effective on species hiding/resting in the vegetation – When applied on surfaces, possible damage to treated surfaces – Quantity of labour required between generalised and localised applications

Conflict of interest

The authors declare that they have no conflict of interest.

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