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# Management of ant pests in urban environments

## Manejo de formigas-praga em ambientes urbanos

## Manejo de plagas de hormigas en entornos urbanos

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**Abstract**
Ants (Hymenoptera: Formicidae) are social insects and important pests in the urban environment. The main groups of pest ants in the urban environment are leafcutter and house ants. Leaf-cutter ants cause crescent-shaped defoliation of plants, where in the urban environment it causes problems in gardens and ornamental plants. Domestic ants cause human health problems, contaminate food and cause problems in equipment and buildings. In this work, we propose an integrated ant management program in urban environments. For that, a bibliographic review was carried out addressing the following topics: life cycle of ants, main groups of pest ants, factors that influence their attack, decision-making systems, management strategies and tactics. It is observed that ants are pests that are difficult to control, and successful control is related to the correct execution of the various components of integrated pest management. Regarding control tactics, chemical control is the main method used to control ants in urban environments because the effectiveness of other methods (ie, biological and behavioral control) is poor.
**Keywords:** Leafcutter ants; Household ants; Influencing factors ants; Decision-making systems; Strategies and tactics of management.

**Resumo**
As formigas (Hymenoptera: Formicidae) são insetos sociais e importantes pragas no ambiente urbano. Os principais grupos de formigas pragas no ambiente urbano são as formigas cortadeiras e as domésticas. As formigas cortadeiras causam desfolhamento em forma de meia lua de plantas, onde no ambiente urbano causa problemas em jardins e plantas ornamentais. Já as formigas domésticas causam problemas de saúde humana, contaminam alimentos e causam problemas em equipamentos e edificações. Neste trabalho, propomos um programa de manejo integrado de formigas em ambientes urbanos. Para tanto, foi realizada uma revisão bibliográfica abordando os seguintes temas: ciclo de vida das formigas, principais grupos de formigas-praga, fatores que influenciam seu ataque, sistemas de tomada de decisão,

estratégias e táticas de manejo. Observa-se que a formigas são pragas de difícil controle, e o sucesso do controle está relacionado à correta execução dos diversos componentes do manejo integrado de pragas. Em relação às táticas de controle, o controle químico é o principal método utilizado para controlar as formigas em ambientes urbanos porque a eficácia dos outros métodos (isto é, controle biológico e comportamental) é deficiente.
**Palavras-chave:** Formigas cortadeiras; Formigas domésticas; Fatores de influência formigas; Sistemas de tomada de decisão; Estratégias e táticas de gestão.

**Resumen**
Las hormigas (Hymenoptera: Formicidae) son insectos sociales y plagas importantes en el medio ambiente urbano. Los principales grupos de hormigas plaga en el medio urbano son las hormigas cortadoras de hojas y domésticas. Las hormigas cortadoras de hojas provocan la defoliación de las plantas en forma de media luna, mientras que en el medio urbano provoca problemas en jardines y plantas ornamentales. Las hormigas domésticas causan problemas de salud humana, contaminan los alimentos y causan problemas en equipos y edificios. En este trabajo, proponemos un programa de manejo integrado de hormigas en entornos urbanos. Para ello se realizó una revisión bibliográfica abordando los siguientes temas: ciclo de vida de las hormigas, principales grupos de hormigas plaga, factores que influyen en su ataque, sistemas de toma de decisiones, estrategias y tácticas de manejo. Se observa que las hormigas son plagas de difícil control, y el éxito de su control está relacionado con la correcta ejecución de los diversos componentes del manejo integrado de plagas. Con respecto a las tácticas de control, el control químico es el principal método utilizado para controlar hormigas en ambientes urbanos debido a que la efectividad de otros métodos (es decir, control biológico y conductual) es pobre.
**Palabras clave:** Hormigas cortadoras de hojas; Hormigas domésticas; Factores influyentes hormigas; Sistemas de toma de decisiones; Estrategias y tácticas de la dirección.

## 1. Introduction

Ants are insects belonging to the order Hymenoptera and the family Formicidae. These insects have social organization and live in colonies divided into castes, in which all individuals perform different functions (Ferguson-Gow et al. 2014; Heinze 2017; Thorne & Traniello 2003). In ecosystems, ants engage in several important roles such as participation in the recycling processes of organic matter, acting as natural enemies of pests on crops and pollinating plants (Drummond and Choate 2011; Pereira et al. 2018; Ramos et al. 2012).

However, in both urban and agricultural environments, some species of ants can be pests (Josens et al. 2017; Lucky 2009). In the urban environment, some ant species might act as pests by attacking plants, causing problems for human health, contaminating food and inducing problems in equipment and facilities (Della Lucia et al. 2014; Zeringóta et al. 2014).

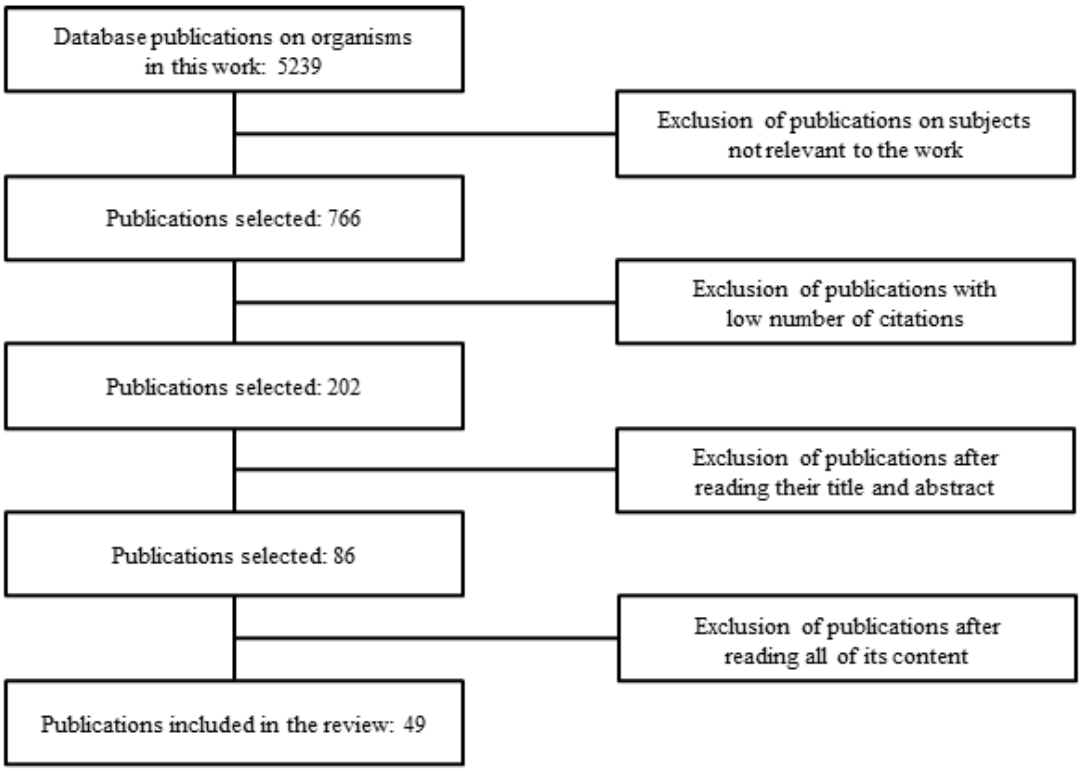
In this research, we propose an integrated management program (IPM) for this pest group in urban environments. Here, we will discuss the ant life cycle, major groups of ant pests in urban environments, factors influencing their attack, decision-making processes for their control, and management strategies and tactics.

## 2. Methodology

In this work, a bibliographic review was carried out to gather information about the life cycle, main groups of pest ants in urban environments, factors that influence their attack, decision-making processes for their control and management strategies and tactics. For this, a narrative review was carried out, in which the results obtained based on readings of available technical-scientific information were presented, bringing a review of the most current data on the topic addressed (Cunha et al., 2014). There is no time frame in the bibliographic material selected for this study.

Data were searched and compiled using Google Scholar search tools. The keywords and indexers used during the search were leafcutter ants, household ants, influencing factors ants and ants control. After reading the materials found, files relevant to the topic to be discussed were pre-selected and later used as a database in writing the review. The criteria for exclusion of literature in this review are described in Figure 1. Table 1 contains the list of references used for each subject.

**Figure 1 -** Selection scheme of included publications.




Source: Own authorship.

**Table 1 -** Identification of studies: Subjects and references.

| Subject | References |
|---|---|
| Bioecology of ants | Drummond and Choate 2011; Ferguson-Gow et al. 2014; Heinze and Wilson 1990; Pereira et al. 2018; Ramos et al. 2012; Thorne and Traniello 2003 |
| Damage from ants as pests | Della Lucia et al. 2014; Zeringóta et al. 2014 |
| Ants life cycle | Collett and Cardé 2014; Della Lucia 2011; Giesel et al. 2013; Gronenberg and Riveros 2009; Moreau 2009; Suarez 2003; Traniello 1989; Tsutsui and Suarez 2003 |
| Leafcutter ants | Della Lucia 2011; Josens et al. 2017; Lucky 2009; Sit et al. 2015 |
| Household ants | Fontana et al. 2010; Klotz et al. 2007; Klotz 2010; Koehler and Pereira 2012; Máximo et al. 2014; Moreira et al. 2005; Pellegrino et al. 2002; Pringle et al. 2014; Vital et al. 2015 |
| Factors influencing ant pests | Cole et al. 2010; Della Lucia 2011; Hölldobler and Wilson 1990; Koehler and Pereira 2012; Rust and Choe 2012 |
| Decision making: ant pest monitoring | Binns and Nyrop 1992; Carroll and Janzen 1973; Della Lucia 2011; Dussutour et al. 2009; Fourcassié and Deneubourg 1994; Klotz 2010; Klotz et al. 2007; Rust and Choe 2012; Rust and Su 2012; Webb and Shine 1992 |
| Environmental manipulation | Della Lucia 2011; Klotz 2010; Klotz et al. 2007; Rust and Choe 2012; Rust and Su 2012; Schoonderwoerd et al. 1997 |
| Behavioral control | Della Lucia 2011; Sharma et al. 2015; Tatagiba-Araujo et al. 2012 |
| Biological control | Della Lucia 2011; Lachaud and Pérez-Lachaud 2012; Morrison et al. 1999; Qiu et al. 2014; Rust and Choe 2012 |
| Chemical control | Araújo et al. 2008; Britto et al. 2016; Della Lucia 2011; Gouvêa et al. 2010; Klotz 2010; Klotz et al. 2010; Koehler et al. Pereira 2012; Li and Chen 2012; Oliveira et al. 2003; Ribeiro et al. 2008; Silverman and Brightwell 2008; Zanetti et al. 2008 |

Source: Own authorship.

## 3. Life Cycle

When an anthill reaches maturity, the colony consists of queens, temporary castes, workers and soldiers. The queen has the reproductive function (since she produces eggs) and keeps the individuals aggregated by producing pheromones (Della Lucia 2011). Depending on the ant species, the colony might have one or more egg-laying queens (Moreau 2009; Tsutsui & Suarez 2003). In some species, when the queen dies, she is replaced by a new queen immediately (Della Lucia 2011). However, in other ant species (such as the genus Atta), the queen is irreplaceable, and when she dies, the colony declines and subsequent extinguishment occurs (Della Lucia 2011; Tsutsui & Suarez 2003).

The temporary castes are composed of winged reproductive individuals who will establish new ant colonies. The nuptial flight of males (kings) and females (queens) belonging to these temporary castes occurs during warmer periods. In tropical regions, the nuptial flight usually occurs in warm periods and when the first rains occur (Della Lucia 2011; Tsutsui & Suarez 2003). After the queens are fecundated, they start the process of founding new colonies. During the flight, most females are killed by predators and adverse environmental conditions. Thus, only a small number of them will be able to establish a new colony. To illustrate, in the genus Atta, only 0.05% of fertile females will found successful nests. When reaching a suitable site for a new nest (e.g., soil, trees or cracks in buildings), the newly mated queen cuts her wings and begins the foundation of the new colony. Workers (who will be responsible for internal and external tasks in the colony) and soldiers (who will be responsible for security in the colony) will emerge in successful colonies (Della Lucia 2011; Tsutsui and Suarez 2003). Once again, when the colony reaches maturity, winged temporary individuals (kings and queens) who will establish new colonies will emerge (Della Lucia 2011; Tsutsui & Suarez 2003).

The habit of foraging and the proportion of the number of ant foragers in relation to the other ants of the colony varies according to the species, the environment and location (Collett a& Cardé 2014; Giesel et al. 2013).

Ant foraging occurs due to a sequence of ant behaviors, and it is a very complex process (Gronenberg and Riveros 2009; Traniello 1989). The first step of foraging involves the choice of food; the ants take into account its color, shape, smell and palatability. In some cases, the pheromone trail is very important to facilitate the location and identification of a food source. The forager ants find food after returning to the nest by marking the site with a typical colony odor; this will be the signal for other forager ants to find the food source (Traniello 1989). Not all individuals leave their colonies to forage. The forager ants are often the largest and oldest (Traniello 1989). The forager ants share the food that is brought to the nest with all the castes of the colony.

## 4. Main groups of Ant Pests in Urban Environments

There are two main groups of ant pests in the urban environment: leafcutter ants and household ants. We will describe below some of their features and the damage caused by these ants.

### 4.1 Leafcutter ants

Leaf-cutting ants of the genus *Atta* are widely distributed on the American continents (Della Lucia 2011). *Acromyrmex* ants can be found in North America (southern USA), Central America and South America (to the center of Argentina). Leafcutter ants build their nests in forests and agricultural areas (most of them in tropical areas).

In urban environments, they attack plants in gardens, trees and homes, causing large problems. The workers of these ants cut plant leaves and transport them to their nest. These leaves will serve as a substrate for the development of a special kind of fungus that serves as a food source for the colony (Della Lucia 2011; Sit et al. 2015). The plants damaged by leaf-cutting ants may become stunted, and this might lead to the plants' death, especially in cities where the air pollution is high (Della Lucia 2011; Josens et al. 2017; Lucky 2009).

Leafcutter ants belong to the subfamily *Myrmicinae*, the tribe *Attini* and the genera *Acromyrmex*, *Atta*, *Mycocepurus*, *Sericomyrmex* and *Trachymyrmex*. The most important species belong to the genera *Atta* and *Acromyrmex* due to their economic importance in America and because the main research and publications on leaf-cutting ants have been concentrated on *Atta* and *Acromyrmex* (Della Lucia 2011). The differences between these two genera are shown in Figure 2.

**Figure 2 -** Soldiers and nests of leaf-cutting ants from genera *Acromyrmex* and *Atta*.

| *Acromyrmex* spp. | *Atta* spp. |
|---|---|
| ➢ The workers have three pairs of spines on the back, and the soldiers are 8 to 10 mm long.  | ➢ The workers have four or five pairs of spines on the back, and the soldiers are 12 to 15 mm in length.  |
| ➢ The nests are superficial and may be covered by plant residues.  | ➢ The nests are deep and occur under the soil from the excavations.  |

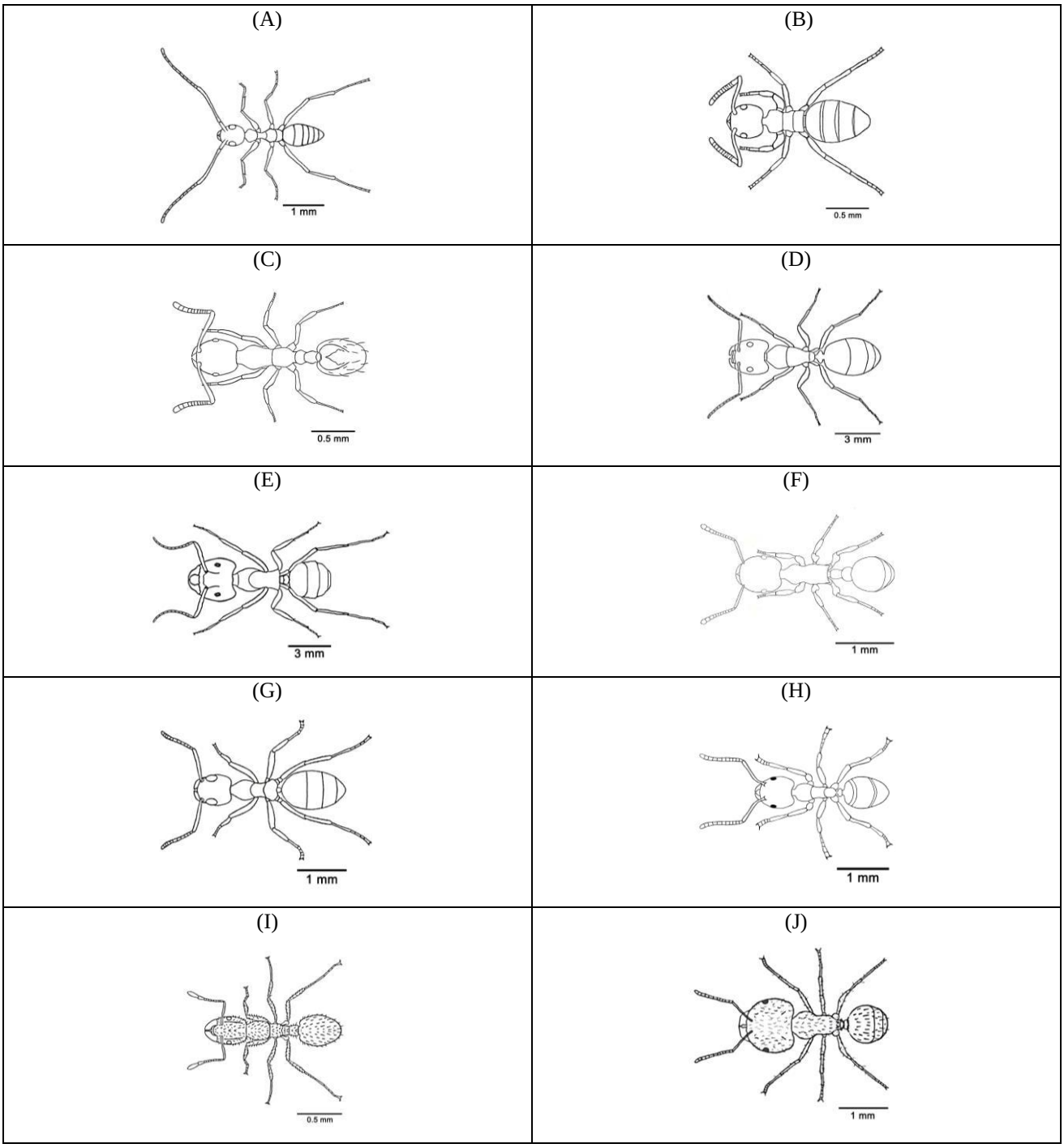
Source: Own authorship.

Description of Figure 2: Figure 2A: Image of the ant Acromyrmex spp.. The workers have three pairs of spines on the back, and the soldiers are 8 to 10 mm long. Figure 2B: Image of the Atta spp. ant. C. The workers have four or five pairs of spines on the back, and the soldiers are 12 to 15 mm in length. Figure 2C: Image of the nest of the Acromyrmex spp.. The nests are superficial and may be covered by plant residues. Figure 2D: Image of the nest of the ant Atta spp.. The nests are deep and occur under the soil from the excavations.

**4.2 Household ants**

The household ants group is formed by a large number of species. The main ants in this group are the longhorn crazy ant (*Paratrechina longicornis*), ghost ant (*Tapinoma melanocephalum*), pharaoh ant (*Monomorium pharaonis*), black carpenter ant (*Camponotus pennsylvanicus*), Florida carpenter ant (*Camponotus floridanus*), pavement ant (*Tetramorium caespitum*), odorous ant (*Tapinoma sessile*), fire ants (*Solenopsis* spp.), tawny crazy ant (*Nylanderia fulva*), Argentine ant (*Linepithema humile*) and the electric ant (*Wasmannia auropunctata*) (Klotz et al. 2007; Koehler et al. Pereira 2012; Vital et al. 2015) (Figure 3).

**Figure 3 -** Main species of household ants: (A) *Paratrechina longicornis*, (B) *Tapinoma melanocephalum*, (C) *Monomorium pharaonis*, (D) *Camponotus pennsylvanicus*, (E) *Camponotus floridanus*, (F) *Tetramorium caespitum*, (G) *Tapinoma sessile*, (H) *Linepithema humile*, (I) *Wasmannia auropunctata* and (J) *Pheidole* spp.




Description Figure 3. Figure 3A: Drawing of the ant *Paratrechina longicornis*. Figure 3B: Drawing of the ant *Tapinoma melanocephalum*. Figure 3C: Drawing of the ant *Monomorium pharaonis*. Figure 3D: Drawing of the ant *Camponotus pennsylvanicus*. Figure 3E: Drawing of the ant *Camponotus floridanus*. Figure 3F: *Tetramorium caespitum*. Figure 3G: Drawing of the ant *Tapinoma sessile*. Figure 3H: Drawing of the ant *Linepithema humile*. Figure 3I: Drawing of the ant *Wasmannia auropunctata*. Figure 3J: Drawing of the ant *Pheidole* spp. In these figures, readers should observe the morphological differences between the ant species. Source: Own authorship.

The household ants group is formed by a large number of species; therefore, they have different morphological characteristics as well as different nesting sites. The household ants build their nests inside and outside buildings. Inside buildings, they build their nests in cracks in the floor, roof or walls (Klotz et al. 2007; Koehler et al. Pereira 2012). In the

external environment, household ants build their nests in trees, wood and rubble. The diversity of locations where household ants establish their nests makes it difficult to locate and control them (Klotz et al. 2007; Koehler et al. Pereira 2012).

Household ants have wide diets in terms of the foods they can eat. Some of these foods include sugar, human food leftovers, animal corpses, and the honeydew produced by sucking insects that attack plants (Pringle et al. 2014). The ways domestic ants cause problems are as follows: act as vectors of human diseases (mostly due to contamination in hospitals and health centers), produce toxins that cause problems in humans and domestic animals, contaminate food, disperse sucking insects on ornamental plants and damage equipment and structures (Máximo et al. 2014).

*Monomorium pharaonis*, *P. longicornis* and *T. melanocephalum* ants are able to carry fungi and bacteria that cause diseases in humans. Approximately 20 species of bacteria have been observed being transported by these ants (Fontana et al. 2010). The bacteria *Klebsiella pneumoniae pneumoniae*, *Staphylococcus* and *Streptococcus* cause hospital infections, and they are carried by household ants (Moreira et al. 2005; Pellegrino et al. 2002). In addition, the fungal genera *Aspergillus* and *Candida* are also known to cause disease in humans and are similarly transported by these ants. However, household ants are less efficient in transmitting disease to humans due to the small amount of bacterial and fungal inocula that they carry (Klotz 2010).

Many of the household ants produce substances that are released during their bites, which are toxic to humans. These substances are usually piperidine alkaloids and proteins, and they can cause redness, burns and respiratory problems in people (Li et al. 2012). In some cases, the problems arising from the ant bites can last more than ten days. The pharaoh ant, for instance, is able to produce and release into residences substances that may act as allergens and cause asthma in people (Koehler et al. Pereira 2012).

Household ants are attracted to sugar and any other foods that humans consume. When household ants come into contact with food, the food can provide an ideal site for bacterial multiplication and transportation, bringing a serious risk of food contamination by enterotoxin production (Moreira et al. 2005).

On the other hand, when these ants build their nests within the structure of buildings, they can compromise the security of these facilities by reducing their resistance (Klotz 2010; Klotz et al. 2007; Koehler and Pereira 2012). In addition, when household ants build their nests in electronic equipment, such equipment can be damaged (Klotz et al. 2007; Koehler et al. Pereira 2012). Another problem that household ants can cause in urban environments is the transport of sucking insects such as aphids, scale insects, flies and leafhoppers, which attack plants in urban environments (Vital et al. 2015).

## 5. Factors Influencing ant Pests

Understanding the factors that influence pest attack is important for planning integrated management programs for pests (Della Lucia 2011). The main factors affecting the populations of ant pests are climatic elements, environmental characteristics and the use of control methods (Della Lucia 2011; Rust & Choe 2012).

Because insects are ectothermic animals, their body temperatures follow the environmental temperature. Therefore, ants generally have higher activity in the summer due to the increased air temperature (Cole et al. 2010). In tropical and subtropical climates, these climatic conditions generally correspond with the occurrence of the first rains and when the nuptial flight occurs (Hölldobler & Wilson 1990).

As mentioned earlier, ant pests in urban environments make their nests inside and/or outside buildings. The material used in the construction of a building has an influence on the establishment of new colonies of ants. Buildings made of wood usually have more locations for ants to establish colonies, and spaces inside the walls are suitable sites for the construction of nests (Della Lucia 2011; Rust & Choe 2012). The existence of cracks in the floors, walls and ceilings of buildings is also an aspect that assists in the establishment of ant nests.

The availability of food also means that there is a large increase in the population of ants. Therefore, non-sealed containers and trash cans containing food or garbage are attractive as food sources to household ants. The failure to perform frequent inspections in buildings to detect an ant attack as well as the lack of adequate control of these pests allows their populations to increase greatly (Della Lucia 2011; Koehler et al. Pereira 2012). This occurs especially when the control of ants is not performed before the nuptial flight and the foundation of new colonies (Della Lucia 2011; Koehler et al. Pereira 2012; Rust & Choe 2012).

## 6. Decision Making: ant pest Monitoring

Decision making is a very important step in the management of pest ants. To make the decision to control or not to control ants, it is necessary that monitoring is undertaken to determine whether there is activity of ants in the area (just after the detection of the activity of ants is when it becomes possible to implement the control method). Monitoring is one prerequisite for effective decision making in IPM (Binns & Nyrop 1992). Therefore, the constant monitoring of ants in a pest management program in the urban environment is essential.

Because ants build nests both inside and outside buildings, it is important that inspections are carried out in these two areas. In addition, the trails of ants should also be identified when possible to allow the localization of the nests (Carroll & Janzen 1973; Webb & Shine 1992).

Some species of ants can leave temporary trail pheromones (Schoonderwoerd et al. 1997), but some others often have well-defined foraging trails such as *Solenopsis molesta*, *Monomorium pharaonis* and the ants of the genera *Atta* and *Acromyrmex* (Dussutour et al. 2009).

The formation of foraging trails is directly linked to the health of the colony and the availability of food. When colonies are starved, a greater amount of foraging traffic is induced if there is no nearby source of food; these ants are able to extend the trails to a wider radius around the nest. Obviously, this means that the closer the major food source is to the nest, the greater will be the numbers of trials and foraging traffic (Fourcassié & Deneubourg 1994). This information is extremely important in case of the use of baits, as they should be arranged closer to the nests and off the trails.

In addition, inspections should be performed both before and after the application of control methods. The former aims to determine where the control measure should be implemented and the latter to verify the control efficiency (Della Lucia 2011; Klotz 2010; Klotz et al. 2007; Rust & Choe 2012).

### 6.1 External environment

In the external environment, both leaf-cutting and household ants should be monitored. The monitoring of leaf-cutting ants is based on the detection of plant defoliation in a half-moon shape and the trails and nests of these insects (Della Lucia 2011). In regard to household ants, the foundations of buildings and the vegetation, organic matter and debris near the buildings should be inspected (Rust and Choe 2012; Rust and Su 2012). These locations should be examined due to the preference of household ants to build their nests in the external environment (Della Lucia 2011; Klotz 2010; Klotz et al. 2007; Rust and Choe 2012).

### 6.2 Inside buildings

Household ants must be monitored inside buildings. The most important species in this environment are the longhorn crazy ant, ghost ant, pharaoh ant, black carpenter ant, Florida carpenter ant, pavement ant, odorous ant, fire ant, tawny crazy ant, Argentine ant, and the electric ant. Inside the buildings, every room must be examined, especially the kitchen, bathrooms, offices and bedrooms (Rust & Choe 2012). Under sinks (especially near pipes), electrical wires, wall corners, doors, windows,

and areas with humidity and near food sources should also be examined. It is important to notice if there are cracks or holes in the floor, walls and ceiling because many ant species use these places to build their nests (Klotz et al. 2007; Rust & Choe 2012). For the carpenter ant, it is important to carry out inspections during the night because this is the time when the ants are most active (Klotz et al. 2007; Rust & Choe 2012; Rust & Su 2012).

## 7. Management Strategies for ant Pests

Strategies are the goals of integrated management programs for pests. The main strategies used in ant management programs in urban environments are (i) reducing the availability of food for the ants; (ii) reducing sites for nesting; (iii) preventing the colonies of ants from proliferating; (iv) maintaining the effectiveness of the methods of control; (v) quickly and efficiently controlling ants; and (vi) using control measures in a way that does not cause problems to human health and also has a low environmental impact (Della Lucia 2011; Klotz 2010; Klotz et al. 2007; Rust & Choe 2012). The procedures to achieve these strategies are discussed in the following sections.

## 8. Management Tactics for ant Pests

Control tactics are used to reduce the population levels of insect pests. In the case of ants, the purpose of control methods is to remove the nests in undesirable locations, which implies the death of the colonies. The tactics and control methods alone or in combination may exclude ants from the desired area. Tactics are the methods used in pest control. In the management of ants in urban environments, control methods should be used together and in a compatible way. Control methods can be divided into tactics of planned use and tactics of use that are dependent on the pest density. Tactics of planned use are used preventively before the pests reach the economic threshold. The choice of tactics of planned use should be prioritized in integrated pest management programs because they have low cost and low environmental impact. However, these tactics (planned use) do not exclude the possibility of pests reaching the economic threshold in a given area; for example, in cases in which monitoring occurs at low frequency and the adoption of tactics occurs belatedly, the use of certain products and inadequate formulations can cause the fragmentation of the colonies and therefore the failure of control. In the management of ants in urban environments, the planned control methods include the manipulation of the environment and natural biological control. Tactics that are dependent on density are used curatively when populations of pests reach the level at which control is necessary. Such control methods that are used in urban environments are applied biological control and chemical control (Della Lucia 2011; Klotz et al. 2007). These tactics (dependent on density) do not exclude the possibility that pests will reach the economic threshold in a given area for the same reasons mentioned previously. Both of these tactics can be used mutually, using one tactic while not excluding the use of the other one.

In urban environments, the aesthetic issue is often more critical than economic issues, and thus economic levels end up not being practical, so aesthetics should be taken into consideration to initiate control actions. Aesthetics can be associated with a specific number of individuals and may be different when we speak of external and internal environments. In indoor environments, control actions against many arthropods such as ants should be initiated at lower density levels, but these levels have not yet been determined. In urban environments (especially indoors), the presence of these insects is a nuisance, and therefore economic damage levels end up being impractical in such cases.

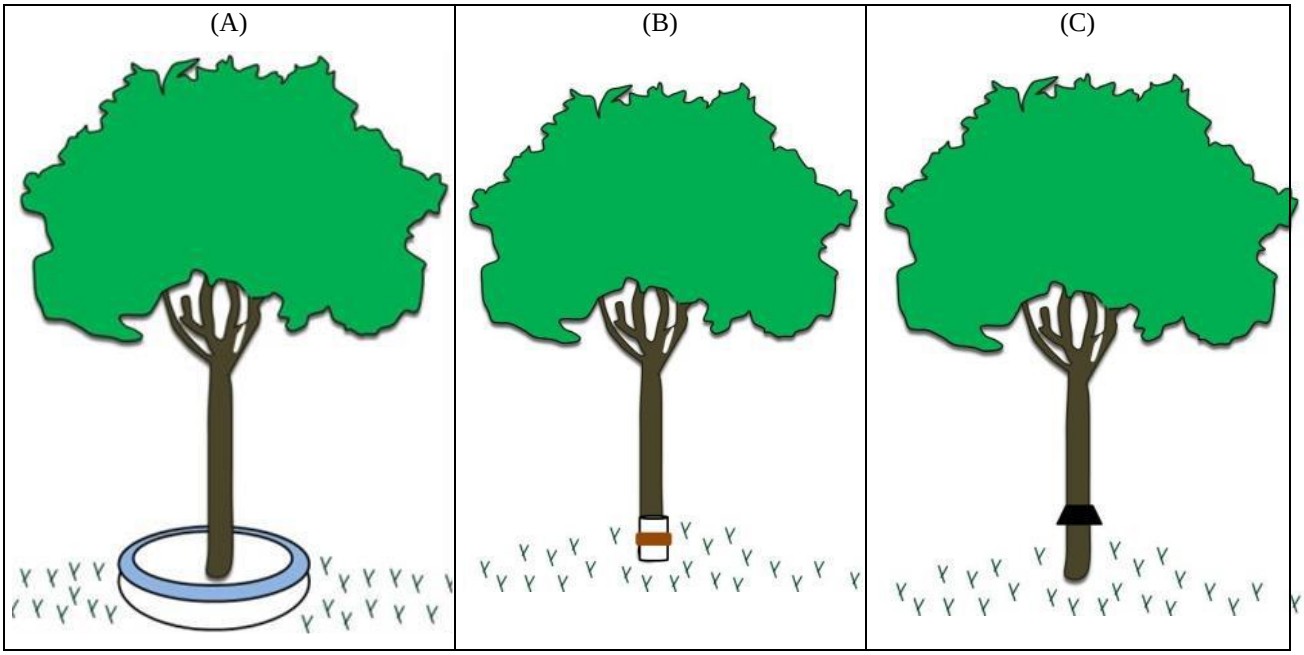
### 8.1 Environmental manipulation

In this control method, sanitary measures are adopted to reduce the availability of food and nesting sites for ants or even to mechanically destroy nests. To reduce the food available to ants, buildings should be cleaned, and containers that contain food or garbage should be sealed (Della Lucia 2011; Klotz 2010; Klotz et al. 2007; Rust and Choe 2012; Rust and Su

2012). For the reduction of nesting sites, holes and cracks in the building structure should be sealed as well. Additionally, debris and wood waste near the buildings should be removed, as they are nesting sites for ants (Klotz et al. 2007; Rust & Choe 2012; Rust & Su 2012).

For the protection of plants against leaf-cutting ants in gardens and home orchards, protective barriers that prevent the ants from cutting the leaves can be used. Such protective barriers that can be used include small water-filled channels around the plants or a physical barrier placed on the stem of the plants. Adhesive glues can also be used as barriers to prevent ants from entering buildings or gaining access to the stems of plants (Della Lucia 2011) (Figure 4).

**Figure 4 -** Main barriers used to protect plants and urban structures against household ants and leaf-cutting ants: (A) water channel around the plants, (B) plastic isolator and (C) physical barrier on plant stem with grease.




Description Figure 4. Figure 4A: Illustration of a barrier against ant attacks on plants using a water channel around it. Figure 4B: Illustration of a plant with a plastic barrier against ant attack. Figure 4C: Illustration of a plant where grease was applied to its stem to prevent ants from causing defoliation. Source: Own authorship.

**8.2 Behavioral control**

This control method includes the use of substances (semiochemicals) that modify the behavior of the pests. In this context, toxic baits are used to control ants. These baits contain an attractive compound and an insecticide (Della Lucia 2011; Sharma et al. 2015; Tatagiba-Araujo et al. 2012). Ants emit pheromones as alarms, for the recognition of individuals, queens, and trails, and for recruitment and territorial marking. Much research has been conducted in an attempt to incorporate these pheromones into the monitoring and control of ants (Della Lucia 2011; Sharma et al. 2015). Despite this effort, there is still no commercial pheromone in use with large-scale success in managing pest ants in urban environments, agricultural areas or forests (Della Lucia 2011; Sharma et al. 2015).

**8.3 Biological control**

Natural biological control of ants occurs during the nuptial flight and is mainly performed by birds, poultry, spiders, beetles, toads, frogs, reptiles and mammals. During the flight, up to 99.95% of ant queens that leave to found new colonies are killed by natural enemies and adverse environmental conditions (Della Lucia 2011; Lachaud & Pérez-Lachaud 2012; Rust & Su 2012).

In anthills that are already established, natural biological control is low, although there are many natural enemies such as wasps and parasitoid flies that can parasitize these colonies (Lachaud & Pérez-Lachaud 2012; Morrison et al. 1999).

Many studies have been conducted in an attempt to commercialize the use of natural enemies for the biological control of ants, especially using entomopathogenic fungi (Morrison et al. 1999; Qiu et al. 2014). Despite this effort, there are currently no natural enemies that have been successfully used at the large scale to control ant pests in the urban environment, agricultural areas or forests (Della Lucia 2011; Lachaud & Pérez-Lachaud 2012; Morrison et al. 1999; Rust & Choe 2012; Rust & Su 2012).

**8.4 Chemical control**

The chemical control of pests can be accomplished with the use of organosynthetic insecticides (conventional chemical control) or natural products (alternative chemical control) (Della Lucia 2011; Koehler and Pereira 2012). In urban environments, the chemical control of ants is performed primarily using four methods; applying the insecticide as a dust (very fine particles of inert carrier with insecticide), a spray, thermonebulization or using baits (Della Lucia 2011; Klotz 2010; Koehler & Pereira 2012).

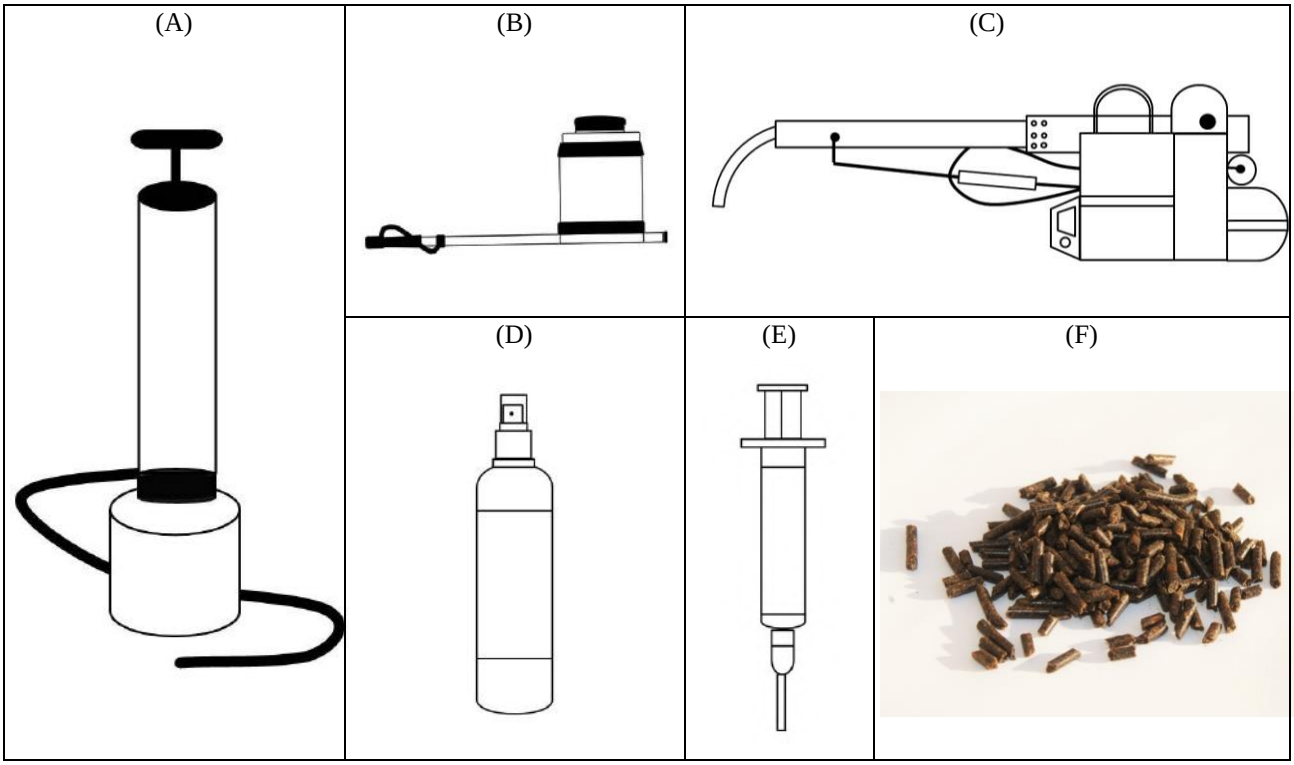
Insecticides as dust formulations are applied inside the anthills for the control of both leaf-cutting ants and household ants (Figure 5A e B) (Koehler & Pereira 2012). These insecticides act through contact and are used to control small colonies (Koehler and Pereira 2012). These insecticides should not be used in humid places or during the rainy season. In humid places, dust adheres to the surface of the nest and does not reach its inner parts. The main insecticides used in dust formulations for ant control are organophosphates and pyrethroids (Koehler & Pereira 2012).

The insecticides applied by spraying are used to control household ants, and these insecticides should be applied to the trails and nest entrances (Figure 5) (Koehler & Pereira 2012; Silverman & Brightwell 2008). The main insecticides used in spraying for the control of household ants are pyrethroids and pyrazoles (Koehler & Pereira 2012; Silverman & Brightwell 2008).

The insecticides applied using thermonebulization are used in the control of leaf-cutting ants, especially ants of the genus *Atta* (Figure 5C) (Zanetti et al. 2008). The equipment used in this method of application is the thermal fogger. This machine has an engine, which heats the oil present in the formulation of the insecticide. This heating creates a smoke that carries the pesticide particles. The smoke impregnates the anthill wall (Britto et al. 2016; Zanetti et al. 2008). Thermonebulization is effective in controlling leaf-cutting ants both in the dry and rainy seasons. This form of insecticide application is effective the control of ants of different sizes. The major limitation of thermal fogging is the high price of the equipment (about US $700 to US $1000). The main insecticides used in thermonebulization for controlling leaf-cutting ants are pyrethroids (Della Lucia 2011).

Ultimately, baits are the main form of insecticide application used in the control of household ants and leaf-cutting ants (Figure 5 E e F). These baits contain an attractive compound and an insecticide. For household ants, sugar is commonly used as an attractant, while orange bagasse is usually used for leaf-cutting ants. These baits are applied to the ant trails, and they are then carried by the ants to the inside of the nest, where they control the insects (Della Lucia 2011; Silverman and Brightwell 2008). In the baits used to control leaf-cutting ants, the most effective active ingredients are sulfluramid and fipronil. Pyrethroids, oxadiazines, abamectin, pyrazoles and neonicotinoids are the main insecticides used to control household ants (Della Lucia 2011; Klotz et al. 2010; Koehler & Pereira 2012).

**Figure 5 -** Insecticide application forms used to control household ants and leaf-cutting ants in urban environments: (A) duster used in insecticide application to control leaf-cutting ants (B) duster used in insecticide application to control household ants, (C) thermal fogger used in insecticide application to control leaf-cutting ants, (D) insecticide used in spraying, (E) insecticide bait used to control household ants (F) insecticide bait used to control leaf-cutting ants.




Description Figure 5: In this figure, readers should observe the methods that can be used to apply insecticides to control ants in urban environments. Figure 5A: duster used in insecticide application to control leaf-cutting ants. the insecticide is placed inside the duster and the hose is placed in the nest. Figure 5B. Duster used in insecticide application to control household ants. The product is placed inside the duster and the product is applied with a hosepipe to the ants. Figure 5C. Thermal fogger used in insecticide application to control leaf-cutting ants. This technique consists of introducing, inside the anthill, liquid ant poison transformed into smoke, through a thermonebulizer. Figure 5D. Image of an insecticide container used in ant control applications. Figure 5E. Image of a syringe with insecticide inside used to control household ants. Figure 5F: Insecticides used for leaf-cutting ants in the form of granulated baits. Source: Own authorship.

Recent research has shown that extracts of *Acmella oleracea* (Asteraceae) (Gouvêa et al. 2010) *Hyparrhenia rufa* (Poaceae) (Oliveira et al. 2003), *Ageratum conyzoides* (Asteraceae) and *Mentha piperita* (Lamiaceae) (Araújo et al. 2008; Ribeiro et al. 2008) are very effective in the control of leaf-cutting ants and household ants. Because these plant extracts have low toxicity to humans, they are very promising in controlling these pests.

## 9. Final Considerations

This review addresses important aspects related to implementing integrated pest management programs for ants in urban environments. As discussed in this paper, ants are pests that are difficult to control, and the success of control is related to the correct execution of the several components of integrated pest management. The correct identification of the species will lead to the knowledge of the preferential habitat of the ants and, consequently, the location of the nests. This information is essential for the monitoring and decision-making processes. Regarding control tactics, chemical control is the main method used to control ants in urban.

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