## CHAPTER 2

## LITERATURE REVIEW

### *2.1 Solenopsis species*

#### 2.1.1 General Taxonomy of Ants

All ants belong to the single family Formicidae within the order Hymenoptera (Bolton, 2007).

#### 2.1.2 Taxonomy of *Solenopsis sp.* (fire ants)

Kingdom : *Animalia*

Phylum : *Arthropoda*

Class : *Insecta*

Order : *Hymenoptera*

Family : *Formicidae*

Sub family : *Myrmicinae*

Tribe : *Solenopsidini*

Genus : *Solenopsis sp.* (Bolton, 2007)

#### 2.1.3 Morphology of ants

Ants undergo complete metamorphosis, passing through a sequence of four stages: egg, larva, pupa, and adult. (eXtension, 2009).

Figure 2.1: Eggs, Larvae and Adult Worker Fire Ant (*Solenopsis sp.)*

**Egg**

An ant's life begins as an egg. Ant eggs are pearly white, soft, tiny and bean-shaped. They are 1 mm long, 0.5 mm in diameter and weighing about 0.0005g, but the queen's egg is many times larger. They have a smooth sticky surface which enables them to bond together in a mass which aids adult ants to move them about more quickly (Jason ,1998).

**Larva**

The larvae of ants are worm-shaped and they have no eyes or legs. Ant larvae are pearly white, just as the eggs. They are covered in tiny hairs that stick to each other; this enables the queen or workers to pick up many at once (Jason ,1998).

**Pupa**

When a larva is large enough, it metamorphoses into a pupa**.** This is a stage of rest and reorganization. Pupae look more like adults, but their legs and antennae are folded against their bodies (Jason ,1998). The pupae of some species spin a cocoon for protection, while others remain uncovered, or naked (eXtension, 2009).

**Adult**

The whole body of the ant is covered with a highly specialized covering, called integument. The integument provides the ant with an exoskeleton that is strong for protection yet flexible for movement. The integument is comprised of three layers: the epicuticle for waterproofing, the procuticle which provides for both strength and flexibility, and the epidermis which is comprised of a single layer of secretory cells. The muscles of the ant are attached directly to the integument. The integument also contains both sensory apparatus and organs for excretion of wastes and signaling chemicals. The integument also houses the spiracles and many of the pheromone excretion and sensory apparatus. Spiracles are tiny valves at the terminal openings of the tracheae through which gaseous exchange takes place (Jason ,1998).

Like other insects' bodies, ants have three major body parts: head, thorax, and gastor (abdomen) (Jason ,1998).

The ant head is composed of three major parts, the eyes, the antennae, and the mouth parts, all of which are contained in or attached to the cranium. The lateral compound eye of ants is composed of many ommatidia, which are in turn composed of several layers: cornea, coneagen layer and retina. It enables them to detect and to commute. They also have the ocelli, or simple eyes, which detect light levels and polarization, on the vertex of the cranium, placed in a triangle. Most of ants have poor eyesight and others are blind altogether (Jason ,1998).

On the head there is also a pair of antennae that help ants detect chemical stimuli, communicate with each other, detect pheromones released by other ants and everything that was in front of them. Sensory apparatus for both tactile and olfactory perception are also found on the antennae. The antennae of *Solenopsis sp.* have 10 segments each and a two-segmented club (Jason ,1998).

Figure 2.2: Head of *Solenopsis sp*. (eXtension 2009)

The mouth is composed of the labrum (upper lip), two strong jaws (the mandibles and the maxillae), the labium (lower lip), and the hypopharynx (tongue). The mandibles are working parts of the mouth used for grasping, tearing, cutting and other special tasks. The maxillae are a pair of acessory jaws. In some species a small pocket inside the mouth holds food for passing to other ants or their developing larvae (Holldobler and Wilson, 2002).

The thorax of the ant where 3 pairs of legs and wings are attached. Every leg is composed of, in order starting at the thorax, a coxa, a trochanter, a femur, a tibia, five tarsal joints, and a claw. The top tarsal segment, called the metatarsal, has a spur protruding from it, which contains a comb used for cleaning the antennae. The hooked claw ends with a ciliated invagination which is capable of creating a vacuum with which the ant can adhere itself to slick surfaces. Most of the males and females would be queens have wings. However, after mating, female ants will shed their wings and become queen ants do not have wings. Worker and soldier ants do not have wings (Holldobler and Wilson, 2002).

The abdomen is composed of three main parts: the petiole, the postpetiole, and the gastor. The petiole is the first characteristic looked at when identifying ants. Ants usually have either 1 or 2 petiole nodes. *Solenopsis sp*. possesses 2 petiole nodes at their abdominal part. The petiole is a unique gland, called the metapleural gland, which contains antibacterial and antifungal chemicals. These antiseptic substances act as a defense against their enemies, and also, are essential for survival under unfavorable condition. The metapleural gland also releases pheromones for communication. The gastor is the last, bulbous structure of the ant, and has a telescoping construction of seven segments. There are many important organs in the metasoma (abdomen), including the reproductive organs. The female ants have a stinger at the end of the abdomen and it is a modified ovipositor (egg laying organ). The ant injects sting repeatedly as it rotates its body with the mandible attached to the skin. *Solenopsis sp.* stings with a venom called Solenopsin (Jason ,1998).

Figure 2.3: *Solenopsis sp*. (eXtension 2009)

**2.1.4 Life Cycle**

The life cycle of the ant consists of four stages: egg, larva, pupa, and adult.

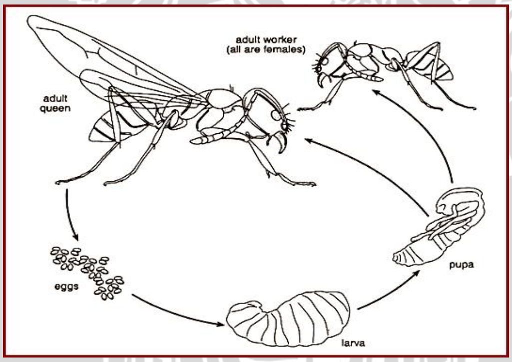


Figure 2.4: Life Cycle of a Fire Ant (eXtension 2009)

The queen is the one that lay eggs. In some species the workers also lay infertile eggs to serve as food for the larvae. Eggs have a pearly color. Worker ants keep them in clusters. The workers clean and rotate the eggs for them not to get moldy (MSU, 2010).

After about 7 to 14 days of cell division, an egg hatches into a worm-shaped larva with no eyes or legs. Larvae are eating machines that rely on adults to provide a constant supply of food (MSU, 2010). The larvae shed their skin many times as they increase in size and start spinning a silky thread. This silky cover is called a cocoon. The larvae now have started their pupa stage (Holldobler and Wilson ,2002).

The larvae change into the pupae stage after about 24 to 27 days. They start out whitish and gradually become darker. They are now ready to take a form of an adult ant and eventually pale yellow ants emerge. They quickly darken as their exoskeleton hardens (MSU, 2010).

The entire life cycle usually lasts from 6 to 10 weeks depending on the species and the environment. Some queens can live over 15 years, and some workers can live for up to 7 years (MSU, 2010).

Furthermore, adult ants belong to one of three castes**:** queen, worker, or male. Fertilized eggs produce female ants (queens, workers, or soldiers); unfertilized eggs produce male ants. Queens are females that were fed more as larvae. They are larger than workers and lay all the eggs in a colony up to millions in some species. Queens initially have wings and fly to find a mate(s), but they tear them off before starting a new colony. A queen can live for decades under the right conditions. Workers are females that were fed less as larvae. They do not reproduce, but perform other jobs, such as taking care of the brood, building and cleaning the nest, and gathering food. Workers are wingless and typically survive for several months. Males have wings and fly to mate with queens. They live for only a few weeks and never help with the chores of the colony (Holldobler and Wilson ,2002).

### 2.1.5 Habitat

In general, *Solenopsis sp*. can be found:

- In the soil

- Near moist areas such as river, banks, pond edges, watered lawns
- Under  timber, rocks and bricks
- Open spaces such as fields, parks and lawns
- On any material that comes from the region inhabited by *Solenopsis sp.*
- In plant pots (MSU, 2010)

Figure 2.5: Fire Ant Mound (eXtension 2009)

**2.1.6 Medical Importance of *Solenopsis sp.***

**2.1.6.1 Venom of *Solenopsis sp*.**

*Solenopsis sp*. are the most common ants that can do harm to lives due to its painful bites. Fire ant bites then pivots to sting with ovipositor. The stinger is a modified ovipositor that consists of a dorsal stylet and 2 ventrolateral lancets. These structures surround the venom canal, which connects to the venom sac. A pair of coiled glands produces the venom that discharges into the venom sac (Ralston *et al.*, 2009).

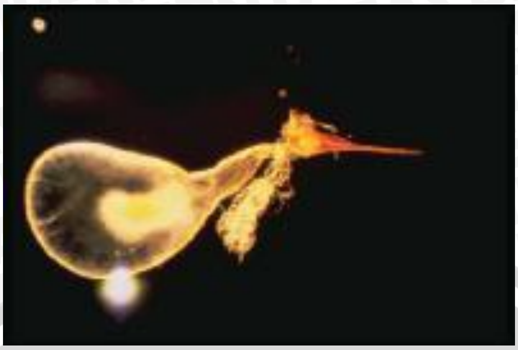

Figure 2.6: Ovipositor with Venom Canal and Venom Sac (Ralston *et al.*, 2009)

The venom is both insecticidal and antibiotic. This venom has not only evolved as a defense mechanism against large predators, it might also be used to protect their eggs and pupae from harmful micro organisms (Ralston *et al.*, 2009).

**2.1.6.2 Common Symptoms of Fire Ant Bite**

For humans, fire ant sting is very painful; a sensation similar to what one feels when burned by fire hence the name fire ant. Fire ant venom differs from bee and wasp venom, which are mostly proteinaceous solutions. Fire ant venom is water-insoluble, nonproteinaceous and contains dialkylpiperidine hemolytic factors (Ralston *et al.*, 2009). These hemolytic factors induce the release of histamine and other vasoactive amines from mast cells, resulting in hemolysis, membrane depolarization and tissue destruction. The stings begin as an intense inflammatory, wheal-and-flare reaction, which becomes a sterile pustule at the sting site. The pustule can leave a scar or lead to secondary infection (Steen *et al.*, 2004).

Figure 2.7: Fire Ant Bite (Ralston *et al.*, 2009)

**2.1.6.3 Severe Symptoms of Fire Ant Bite**

The fire ant venom also contains several allergenic proteins. These protines induce hypersensitivity responses (IgE) , including anaphylaxis (Ralston *et al.*, 2009). Anaphylaxis is a very serious reaction that requires immediate medical attention. Common symptoms of anaphylaxis are swelling of the throat or face, nausea, dizziness, severe chest pain, low blood pressure, severe sweating and slurred speech. If left untreated, anaphylaxis is often lethal. Large, local reactions rarely can cause edematous tissue compression, leading to vascular compromise of an extremity. In severe cases, the victim can even die (Steen *et al.*, 2004).

## 2.2 Sulfur

### 2.2.1 General Description

Elemental Sulfur, also known as Brimstone in its natural state, has been recognized for thousands of years. Sulfur is a non-metallic element that occurs in both combined and free states and is distributed widely over the earth's surface. Its atomic number is 16 and is of atomic mass 32.06 $g.mol^{-1}$. It is taseless, odorless, insoluble in water, and often occurs in yellow crystals or masses. It is one of the most abundant elements found in a pure crystalline form. The word sulfur means "burning stone", and was used almost interchangeably with the term for fire. Because of its combustibility, sulfur was used for a variety of purposes at least 4,000 years ago (Davis and Detro, 2008).

Although it is plentiful on a world scale, native sulfur is usually found in relatively minute quantities. The greatest quantity of naturally occurring sulfur by far is combined with other elements, most notably the sulfides of copper, iron, lead, and zinc, and the sulfates of barium, calcium (commonly known as gypsum), magnesium, and sodium. The large underground sulfur deposits of the Texas and Louisiana salt domes were exploited by a mining technique, and provided the world with a new source of high-purity (99.5%) elemental sulfur. Volcanic deposits are currently exploited in Indonesia and in Chile and other parts of South America (Davis and Detro, 2008).

Secondary sources of sulfur today are the sulfur dioxide (SO2) obtained from industrial mineral, wastes, and flue gasses, and the hydrogen sulfide (H2S) found in "sour" natural gas, petroleum refinery products, and coke-oven gasses.

Sulfur has become one of the basic materials of industrial production. In the United States, more than 12 million long tons are consumed. Sulfur is used to make gunpowder, matches, phosphate, insecticides, fungicides, and medicine, and in vulcanizing rubber and impregnating wood and paper products. But these are only minor uses. Nearly 90% of the domestic production is converted to sulphuric acid. This workhorse of chemistry is a major component in the manufacture of thousands of products, but especially fertilizer. About one-half of sulfur goes to the fertilizer industry (Davis and Detro, 2008).

### 2.2.2 Physical Properties of Sulfur

Sulfur is a tasteless and light yellow solid and has a faint odor. Sulfur appears in a number of different allotropic modifications: rhombic, monoclinic, polymeric, and others. Sulfur is insoluble in water but soluble in carbon disulfide and, to a lesser extent, in other nonpolar organic solvents, such as alcohol, ether, benzene and toluene. It has density of 2.07 $g.cm^{-3}$ at 20 °C. Its melting point is 113 °C and boiling point is 445 °C (Davis and Detro, 2008).

Figure 2.8: Element Sulfur (Google Images)

### 2.2.3 Chemical Properties of Sulfur

Solid sulfur predominates as a ring of eight atoms, but other rings with fewer atoms are also found. Sulfur burns with a blue flame and gives off sulfur dioxide, notable for its peculiar suffocating odor. Sulfur is a very reactive element that combines with most other elements, except gases, gold, and platinum, under favorable circumstances (Davis and Detro, 2008). Chemically, sulfur can act as either an oxidant or reductant. It oxidizes most metals and several nonmetals, including carbon, which leads to its negative charge in most organosulfur compounds, but it reduces several strong oxidants, such as oxygen and fluorine (Davis and Detro, 2008).

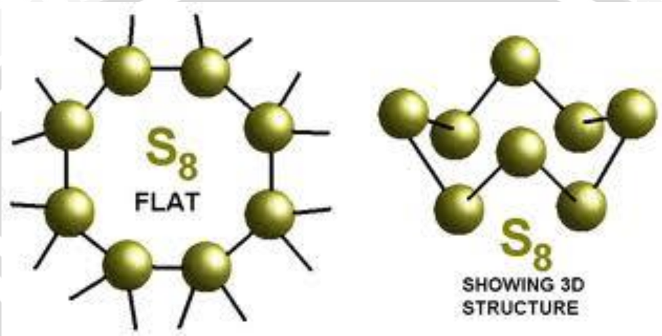


Figure 2.9: Structure of Sulfur ($S_8$) (Google Images)

**2.2.4 Uses of Sulfur**

The major derivative of sulfur, sulphuric acid (H2SO4), is one of the most important elements used as an industrial raw material. Sulfur is also used in batteries, detergents, gun power, matches and fireworks and in the manufacture of rubber products, such as tires. Other applications are making corrosion-resistant concrete which has great strength and resistancy, for solvents and in a host of other products of the chemical and pharmaceutical industries. Agricultural sulfurs are formulated for use as pesticides, fungicides, plant nutrients, fertilizers, and soil amendments (Marshall *et al.*, 2010).

**2.2.5 Health Effects of Sulfur**

All living things need sulfur. Sulfur is a macronutrient for both plants and animals. Sulfur, as a part of the amino acid methionine and cysteine, is used to make proteins and nucleic acids, such as DNA. It also occurs in many essential enzymes. An average person takes in around 900 mg of sulfur per day, mainly in the form of protein. A person who does not get enough sulfur in his or her diet develops certain health problems. These include itchy and flaking skin and improper development of hair and nails. In very rare cases, a lack of sulfur can lead to death (Lenntech, 2013).

Plants also require sulfur for normal growth and development. When plants do not get enough sulfur from the soil, their young leaves start to turn yellow. Eventually, this yellowing extends to the whole plant. The plant may develop other diseases as a result (Lenntech, 2013).

In fact, sulfur is still used to treat certain medical problems. Creams made with sulfur were used to treat infections and diseases. Washed sulfur is also used as a laxative, a substance that helps loosen the bowels. Ground sulfur is essentially non-toxic through skin contact, ingestion and inhalation. However, it can irritate the skin and eyes as well as the respiratory system. Sulfur deposited on skin can be washed away with mild soap and water. Eyes that have come into contact with sulfur dust are to be flooded with water for at least 15 minutes. An inadequate attempt may actually increase the inflammation (Lenntech, 2013).

### 2.2.6 Insecticides

Numerous different insecticides have been developed over the years. The key to a good insecticide is to find a chemical that selectively kills the unwanted plant, animal or fungus without causing damage to the surrounding environment. Each class of insecticide has a different mechanism of action based on its chemical structure. Some insecticides are highly toxic to humans while others have relatively low toxicity (Squibb, 2013).

Generally, most insecticides act by poisoning the nervous system of target organisms including human if the dose is sufficiently high. Organophosphate pesticides act primarily at the synapses, altering the regulation of the transmission of the nerve impulse from one cell to the next. They inhibit the enzyme, acetylcholinesterase, which breakdown the neurotransmitter, acetylcholine. The active part of the OP (organophosphate) insecticides is the phosphate group sharing a double bond with either an Oxygen or a Sulfur group (Squibb, 2013).

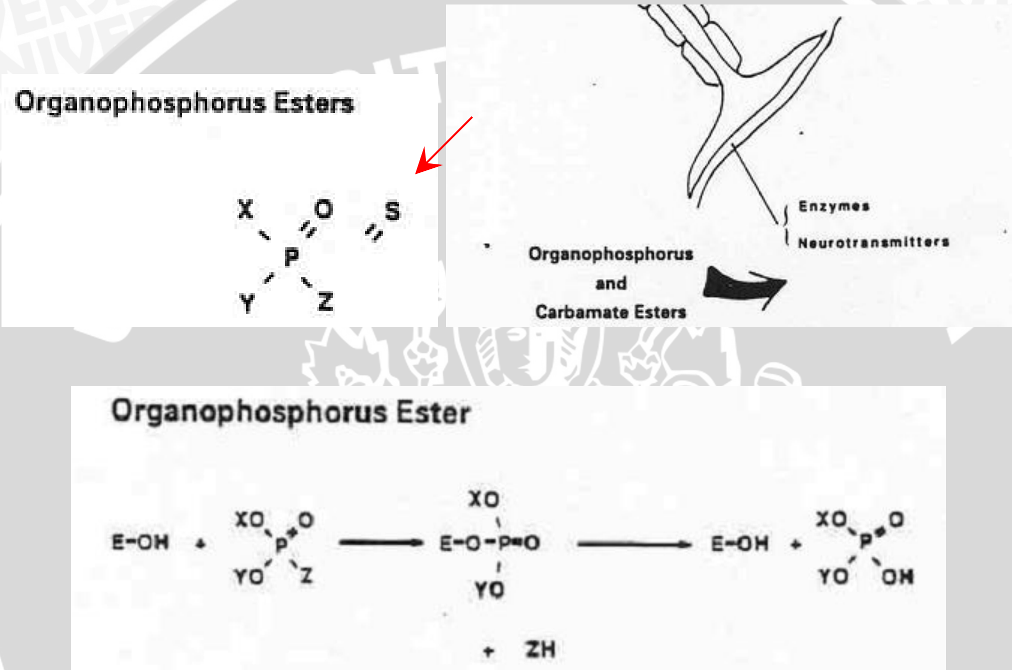


Figure 2.10: The interaction between an organophosphorus ester with the hydroxyl group in the active site of the enzyme acetylcholine esterase (E-OH) (Squibb, 2013)

### 2.2.7 Insecticidal Effect of sulfur

Elemental sulfur is probably the oldest effective pesticide in use today, and it remains popular because of its low toxicity to humans; the only elemental inorganic pesticides still in wide use today are arsenic, boron, copper and sulfur. Sulfur has been registered for pesticide use in the United States since the 1920s (Win, 2010). Sulfur has direct suppressive effects on both pests and predatory mites with no negative effects on plants or soil (Davis and Detro, 2008). Sulfur can be purchased alone or mixed with other insecticides and inorganic fungicides to control a wide variety of garden pests and is an active ingredient in nearly 300 registered pesticide products (Win, 2010).

**2.2.7.1 Available Formulations**


Figure 2.11: Sulfur Plant Fungicide and Insecticide (Google Images)

Sulfur is available in three major formulaions: sulfur dust (small sulfur particles mixed with 1% or 5% clay of talc to enhance its spread and adhesion), wettable sulfur (finely ground sulfur particles mixed with wetting agent to make sulfur soluble in water) and colloidal sulfur (extremely small sulfur particles mixed with water formulated as a wet paste) (Marshall *et al.*, 2010).

**2.2.7.2 Mechanism of Action**

Sulfur disrupts the metabolic processes of fungi and other target pests that absorb it and use it in replace to oxygen (Tomlin, 1994). Sulfur is the active substance of lime sulfur (calcium polysulfides). Lime sulfur can be used as an insecticide and acaricide to control over wintering insects such as mites, scales and aphid eggs. The effectiveness of lime sulfur is due to sulfur which can take up large amount of oxygen as represented in the equation: $CaS_5 + 3O = CaS_2O_3 + 3S$ (List, 1929). This reducing power of sulfur appears to be the most important in making lime sulfur an efficient insecticide. In this way, the lime sulfur softens or partially dissolves the newly secreted wax that makes part of insect's exoskeleton, softening them. In general, the insecticidal effects of lime sulfur are due principally to the following named properties: 1) Its power to take up large amounts of oxygen; 2) Its ability to soften the newly secreted wax at the insect's exoskeleton; 3) The amount of free sulfur formed in its decomposition (List, 1929).

**2.2.7.3 Safety**

Sulfur is less toxic to humans than many other conventional synthetic fungicides and miticides. However, precautions should be taken to prevent inhalation of the dust which can damage the lungs or skin or eye contact with sulfur compounds which are strong irritants. A dust mask, goggles and the protective clothing should be worn (William *et al.*, 1995).