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# The development of a photographic atlas of plant adaptations for pollination

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# THE DEVELOPMENT OF A PHOTOGRAPHIC ATLAS OF PLANT ADAPTATIONS FOR POLLINATION

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## ABSTRACT

Plants have biotic, abiotic, or both biotic and abiotic adaptations for pollination, depending on how they are structured and the attraction between the plant and pollinator. The main focus for this project was biotic adaptations for pollination, and how various plants are specifically structured for the insect, bird, or mammal to pick up the pollen and carry it to the next plant. Documentation, using image/focus stacking and macro photography, was done of the structures of various plants from the University of Northern Iowa (UNI) Botanical Center to support the reason for why plants are structured the way they are. While documenting the various plants, new information was discovered about how plant anatomical structures assist in pollination. The structure of a flower and its placement of the reproductive organs seem to be correlated with the type of pollinator of that flower. Some of the patterns observed in certain flowers based on their pollinators included a landing platform, a tubular flower structure, and a specific placement of the reproductive organs within the flower. These patterns were not collectively seen in one flower, but varied in flowers based on the pollinator.

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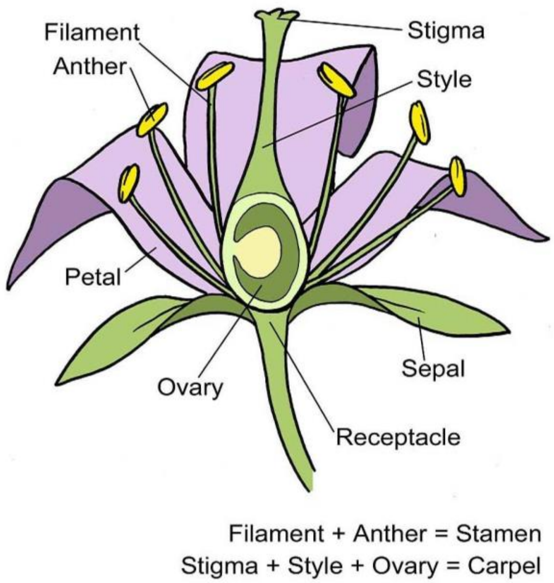
## INTRODUCTION

Floral structure is extremely important in pollination. Most plants have the same general structure, consisting of the pedicel, receptacle, sepals, petals, stamens, and carpels. The pedicel is the flower stalk, and the receptacle is at the very end of the axis where the other flower parts are attached. Sepals are modified leaves that surround and enclose the flower parts as they mature, protecting the flower bud as it develops. When the pollen and megaspores, which are in the ovules, are ready, the sepals bend outward, and the flower opens. Petals are leaf-like, and each plant species has petals of distinctive size, shape, color, and arrangement, allowing pollinators to recognize specific plant species. The male reproductive part of the flower is the stamen, collectively called the androecium. The stamen is located above the petals and produces pollen. It consists of the filament, or stalk, and the anther, where the pollen is actually produced. On the other hand, the carpel is the female reproductive part of the flower, collectively called the gynoecium. The carpel is located at the highest level on the receptacle. It consists of the stigma, style, and ovary. The stigma catches the pollen grains, the style elevates the stigma to a useful position, and the ovary is where the megaspores are produced. Inside the ovary are the ovules which develop into seeds once the egg is fertilized (Mauset, 2017). An image of the described anatomical structures can be seen below, all of which are important in the protection and pollination of the plant.

Figure 1- Anatomical Structure of a Typical Flower (Royal, 2015):




One type of pollination is cross-pollination, which is pollination of a carpel by pollen from a different flower (Mauseth, 2017). There are many ways the pollen can reach the carpel of the other flower, one of which is pollination by animals. About 80% of all plant pollination is by insects, birds, mammals, and other animals (USDA Forest Service). As the pollinator feeds at the flower, pollen is placed on a part of its body. When it visits the next flower, the pollen is rubbed directly onto the stigma. Many flowers and insects, birds, and mammals have undergone coevolution so that the flower becomes adapted for visitation by a particular animal and the animal becomes adapted for efficient exploitation of the flower (Mauseth, 2017). This coevolution in plant species can be seen in the shape of the flower and different arrangements of the reproductive structures.

In regards to the shape of the flower, most flowers are radially symmetrical, where any longitudinal cut through the middle produces two halves that are mirror images of each other. On the other hand, all insects, birds, and bats are bilaterally symmetrical, where only one longitudinal plane produces two halves that are mirror images. To compensate for this difference in symmetry between plant and pollinator, many flowers and pollinators have coevolved so that the flowers are also bilaterally symmetrical, or zygomorphic. When a pollinator approaches a zygomorphic plant, only one orientation will fit the pollinator's head or body in the flower's distinctive shape (Mauseth, 2017).

Flower shape provides visual cues to assist in plant pollination. Different shapes of the flowers are more adapted to specific pollinators, and this is one reason why plants are structured the way they are. For example, beetle-pollinated flowers tend to have larger and more open flowers, providing an easy landing pad since beetles are not as agile in flight (USDA Forest Service). The landing pad is usually the abaxial petal, which is farthest away from the shoot apex and is typically the lower surface of the mature petal (Mauseth, 2021). Non-hovering pollinators also require these abaxial petal landing pads on the flower so they can rest when picking up the flower's pollen. Another example of visual cues are the long nectar spurs of plants. Spurs are outgrowths of tissue on different plant organs (Ness, 2003). These spurs allow the nectar to be accessed by hawkmoths, butterflies, and hummingbirds, which access the nectar with a long proboscis, another word for a long narrow bill. The long nectar spurs also protect the nectar from being stolen by robber insects (USDA Forest Service). These are only a few examples of how flower shape attracts certain pollinators, but the information in the tables below provide more examples of what flower shape is preferred by what pollinator. The information in the tables below is gathered from the articles "Plant Pollination Strategies" (USDA Forest Service) and "Pollination Mechanisms and Plant-Pollinator Relationships" (Galen, 2017).

Table 1- Pollinators and their Preferred Flower Shape.

| **Pollinator:** | Bats | Bees | Beetles | Birds |
|---|---|---|---|---|
| **Flower shape:** | Bowl-shaped. | Shallow, have a landing pad, and bowl or cup-shaped. | Large, bowl-like or cup-like. | Large, funnel-like, cup-like, and strong perch support. |

Table 2- Pollinators and their Preferred Flower Shape.

| **Pollinator:** | Butterflies | Flies | Moths | Hummingbirds | Ants |
|---|---|---|---|---|---|
| **Flower shape:** | Narrow tube with spur or bowl-shaped, and wide landing pad. | Shallow, and funnel-like or bowl-shaped. | Tubular without lip-like petals. | Tube-shaped with petals forming into spurs (contain nectar). | Cup-shaped or bowl shaped. |

Along with the general flower shape, the slightly different arrangements of the reproductive structures make the plant more adapted for a specific pollinator. However, not much is known about how these arrangements are suited for specific or general pollination, or how they may protect the plant from the “wrong” pollinators. Of the information found, staminal scales, size and shape of pollen/nectar-holding structures, stylar extension, and pistil morphologies play important roles in the arrangement of the reproductive structures involved in plant pollination. Staminal scales are petal-like structures found at the base of the stamens, and they are connected to one another by a ‘bridge’ between the stamens (Riviere, 2013). They function in restricting pollinator access to nectar or pollen, and in ovary/ovule protection. The relative proportions of staminal scales and proboscis/nose length of the animal appear to be crucial for the success of pollinators (Naghiloo, 2020). For example, the *Ropera* plant species is pollinated by bees and wasps, and the staminal scales seem to limit the access of pollinators to nectar due to enclosing the ovary as a cup-shaped structure. The nectar can be accessed when bees and wasps insert their proboscises from the top of the staminal scales' tube, or by laterally pushing the staminal scales aside. This causes the nectar to be accessible only to visitors with a proboscis longer than the staminal scales. Short-tongued bees, wasps, and pollen wasps are excluded from *Ropera* flowers due to the inability to access the nectar (Naghiloo, 2020). This is one example of how stamen structure influences what pollinates the *Ropera* plant species, and we can assume that the presence of staminal scales in additional plant species may influence the types of pollinators of those flowering plants.

In addition to the stamen, the pollen/nectar-holding structures impact pollinator activity. The pollen and/or nectar is the "food" of the plant and is the reason why animals visit the flowers in the first place. In species with hidden nectar, the relative shape and size of the visitor's mouthparts compared to the shape and size of the nectar-holding structure are essential in determining the visitor's access to the nectar and its efficiency as a pollinator (Naghiloo, 2020). The nectar is usually held in the corolla tube, which is collectively the petals of a flower, but it can also be in a spur. If nectar is secreted inside the corolla or in a spur, it is protected against evaporation and is available for specific, restricted groups of pollinators (Brzosko, 2021). But, if the pollinator's mouthparts do not fit with the corolla tube, the pollen from the anthers cannot be accessed and pollination will not occur. Sometimes the nectar is not protected inside the corolla or in a spur, but instead it is exposed. Exposed nectar may be collected by pollinators representing different morphological and ecological types and is more vulnerable to evaporation and robbery (Brzosko, 2021). In this case, the plant may not have a specific pollinator since the nectar is exposed to a wide variety of pollinators.

Pistil factors also control pollination. Pistils are the union of one or more carpels, which consist of the female reproductive structures of the plant (Ness, 2003). The style is part of the carpel, and it facilitates pollen capture. How high the style elevates the stigma to catch the pollen grains may differ in plants depending on the specific pollinator. Stylar extension and the wide variety of pistil morphologies reflect the different pollination mechanisms found among flowering plants (Sanchez, 2004). Some of these pistil morphologies include barriers. To prevent being pollinated by the “wrong" pollinator, many plants have developed barriers that operate in the pistil either before fertilization, inhibiting growth of the pollen tube, or after fertilization, causing abortion of the illegitimate embryo (Sanchez, 2004). Inhibiting the growth of the pollen tube may result from how the pistil and female reproductive parts are arranged and structured in the plant. This shows that the pistil plays an important role in the prevention of gene flow between species and in the maintenance of the species (Sanchez, 2004).

As seen from the information above, much is known about how flower/petal structure impacts the type of animal pollinator of the specific plant. On the other hand, not much is known about if the slightly different arrangements of the reproductive structures influence the specific pollinator of the plant. Since petal structure influences pollination, it is likely that reproductive anatomical structures also influence pollination. This project analyzed and documented those anatomical structures that participate in pollination.

## CENTRAL THEMES ADDRESSED

Plants have various structures and biotic adaptations for pollination, depending on the type of pollinator. Documentation was done to specifically show the detailed structure of the plant to support this central theme. Additional details about how plant anatomical structures assist in pollination were found from this work.

## METHODOLOGY

In order to obtain detailed and magnified images of the internal structures of the flowers, macro photographic techniques and focus stacking techniques were used. Macro photographic techniques used a reversed lens attached to a bellows. This was incorporated with focus stacking techniques (Helicon Focus software), which allowed close-up, magnified images with greater depths of field to be obtained. These techniques were used on a variety of plant specimens provided by the UNI Botanical Center, with assistance from Stephanie Witte and Hannah Gilchrist-Loy. The plant specimens that were documented were taken from the UNI Botanical Center and brought to the lab where macro photographic and focus stacking techniques were used.

When macro photographic techniques were used, a flower was set into position in front of the camera. If the Nikon 85mm f/3.5 macro lens was used, the forefront of the flower was brought into focus using the lens focusing ring. Then, the built-in metering in the camera was used, and a picture was taken. The picture was then evaluated for color, clarity, and brightness. Once the proper color, clarity, and brightness were obtained, subsequent images were taken with these exact same settings, along with the same aperture opening and for the same amount of time (shutter speed). The focus in each subsequent image was slightly altered, such that deeper portions of the flower were brought into focus. One cannot bring the entire flower into focus, front to back, with a single photograph, so the slight changes in focus allowed the different planes of the flower to be in focus in each image. Each picture, with different portions of the flower in focus, were then “stacked,” or overlaid, using Helicon Focus software. This combined all of the photos into one photograph, with the resulting one photograph providing an in-focus image of the entire flower from front to back.

An even greater magnification than the method described previously was obtained in some cases by using a small millimeter lens, and by reversing the lens on a camera bellows. This still used macro photographic techniques, but now the back of the lens faced forward, with the front of the lens attached to the camera with reversing rings and a bellows used. Depending upon the size of the lens, magnification was increased or decreased. Smaller focal length lenses, such as lenses less than 35 millimeters, provided a greater magnification than longer focal length lenses when reversed. In this technique, focus was achieved by moving the lens further away or closer to the object being photographed. A focusing rail, which made fine adjustments in focusing from the front to the back of the flower, was used. Figures 2 and 3 show this technique that was used for this research. After multiple images were taken, with different planes of the flower in focus, Helicon Focus software was used to stack the resulting images. The final result was one image that was in focus from front to back.

Figure 2- Macro Photographic Technique with a Bellows.

Figure 3- Macro Photographic Technique with a Bellows.

**RESULTS**

Table 3- Comparison of the Flowers and their Pollinators.

| | Bees | Butterflies | Moths | Humming-birds | Flies | Small wasps |
|---|---|---|---|---|---|---|
| *Clerodendrum ugandense* | ✓ | ✓ | | | | |
| *Vitex agnus* | ✓ | ✓ | | | | |
| *Plumbago auriculata* | ✓ | ✓ | | | | |
| *Stanhopea oculata* | ✓ (only orchid bees) | | | | | |
| *Asclepias curassavica* | | ✓ | | | | |
| *Hoya carnosa* | | | ✓ | | | |
| *Cestrum nocturnum* | | | ✓ | | | |
| *Bougainvillea glabra* | | ✓ | ✓ | ✓ | | |
| *Cuphea ignea* | | ✓ | | ✓ | | |
| *Huernia zebrina* | | | | | ✓ | ✓ |
| *Frerea indica* | | | | | ✓ | ✓ |
| *Eriobotrya japonica* | | | | | ✓ | |

*A. Clerodendrum ugandense* (Butterfly flower)

*Clerodendrum ugandense* is characterized by four light purple, lateral petals and one darker purple, downward-pointing petal. The long stamens with distal, brown anthers, along with the split stigma and style, arch over the petals. This flower is mainly pollinated by bees, but may also be pollinated by butterflies. The stamens serve as a landing platform for the pollinators. See Figure 4c for labeled reproductive structures.

Figure 4a- *Clerodendrum ugandense* (Butterfly flower).

Figure 4b- *Clerodendrum ugandense* (Butterfly flower).

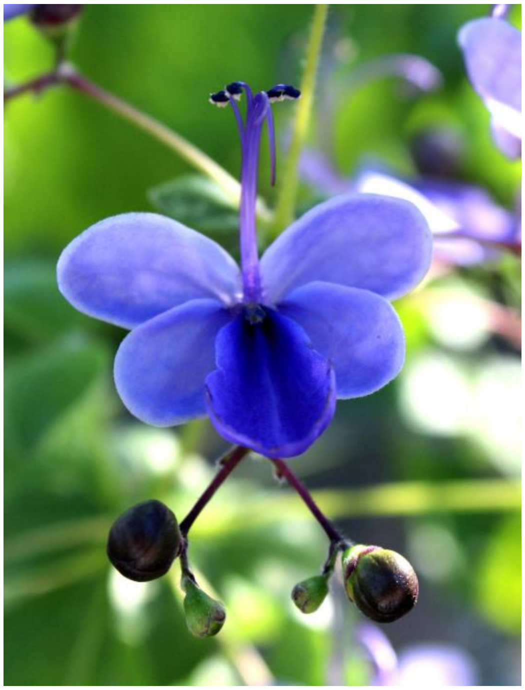
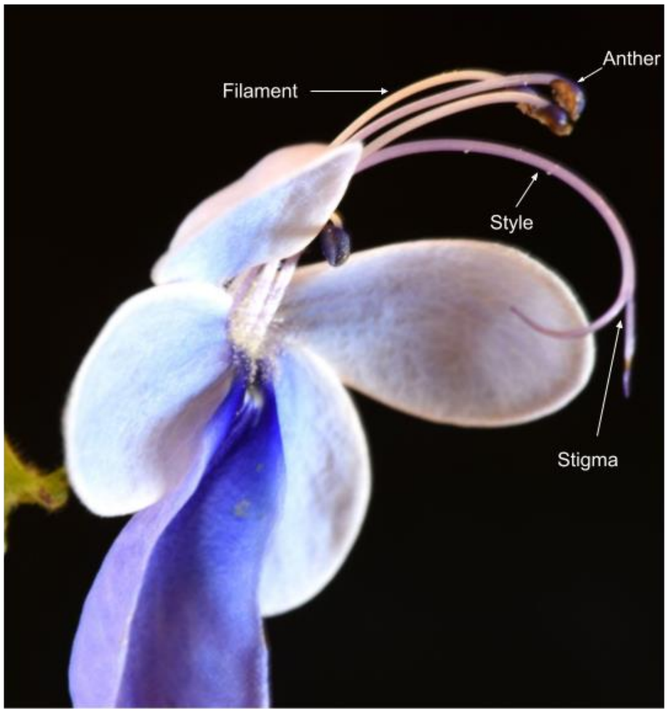


Figure 4c- Labeled *Clerodendrum ugandense* (Butterfly flower).



B. *Vitex agnus* (Chaste tree).

The *Vitex agnus* is characterized by five petals, with one of these being slightly larger and cup-shaped. The stamens and anthers, and style and stigma protrude outward from the petals, arriving at about the same height. This flower is pollinated by bees and butterflies. The stamens may serve as a landing platform for the pollinators. See Figure 5c for labeled reproductive structures.

Figure 5a- *Vitex agnus* (Chaste tree).

Figure 5b- *Vitex agnus* (Chaste tree).

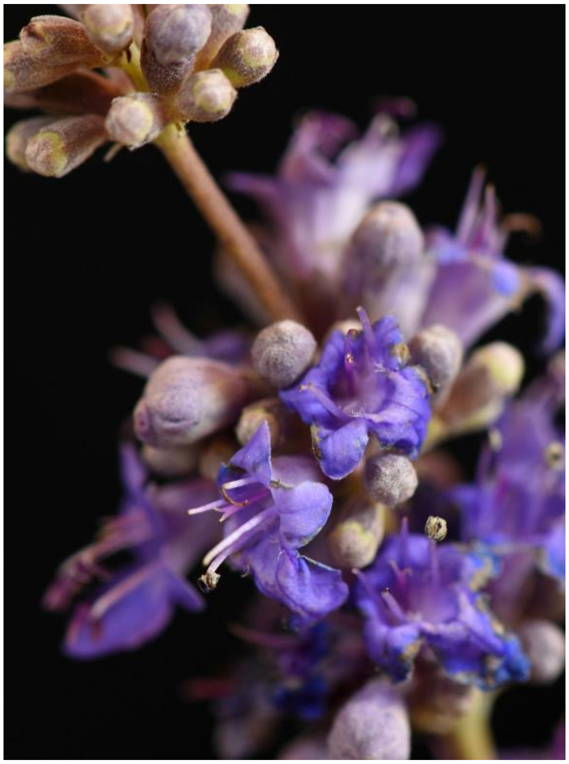


Figure 5c- Labeled *Vitex agnus* (Chaste tree).

C. *Plumbago auriculata* (Cape plumbago; Sky flower).

The *Plumbago auriculata* flower is characterized by light purple petals that spread outward from the center of the flower. The branching stigma, with its style, rises far above the brown anthers. The long-style morphology of this flower allows pollination to occur by pollinators with certain proboscis lengths. This flower is pollinated by bees and butterflies. See Figure 6c for labeled reproductive structures.

Figure 6a- *Plumbago auriculata* (Cape plumbago; Sky flower).

Figure 6b- *Plumbago auriculata* (Cape plumbago; Sky flower).

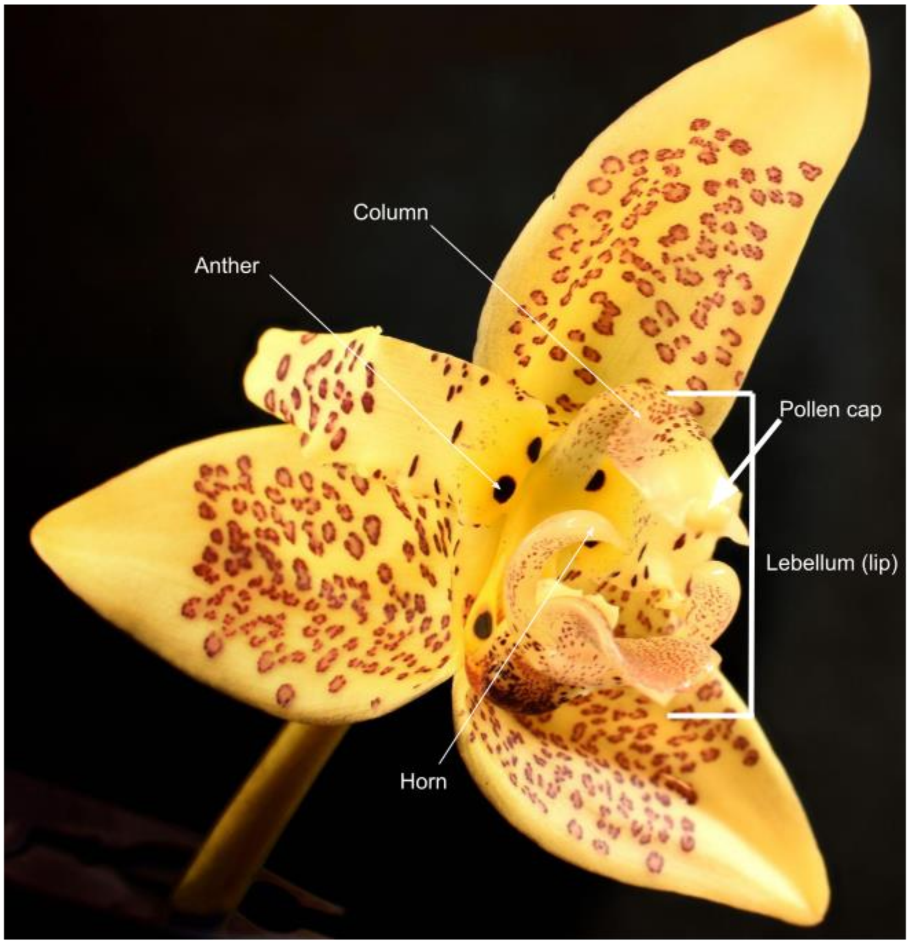
Figure 6c- Labeled *Plumbago auriculata* (Cape plumbago; Sky flower).

D. *Stanhopea oculata* (Orchid flower).

The *Stanhopea oculata* has a unique structure designed for its orchid bee pollinator. The column contains the pollen cap, and arches over the horns. The column is the organ where the female reproductive organs are contained. The labellum, or lip, contains the column and horns, creating a tight space. The tight space between the column and horns allows the orchid bee to be positioned so that the pollen cap is removed, and the pollen is deposited on the back of the bee. This action also allows access to the stigma, which is inside the column, to allow pollination to occur by the next orchid bee carrying the pollen. See Figure 7b for labeled reproductive structures.

Figure 7a- *Stanhopea oculata* (Orchid flower).

Figure 7b- *Labeled Stanhopea oculata* (Orchid flower).

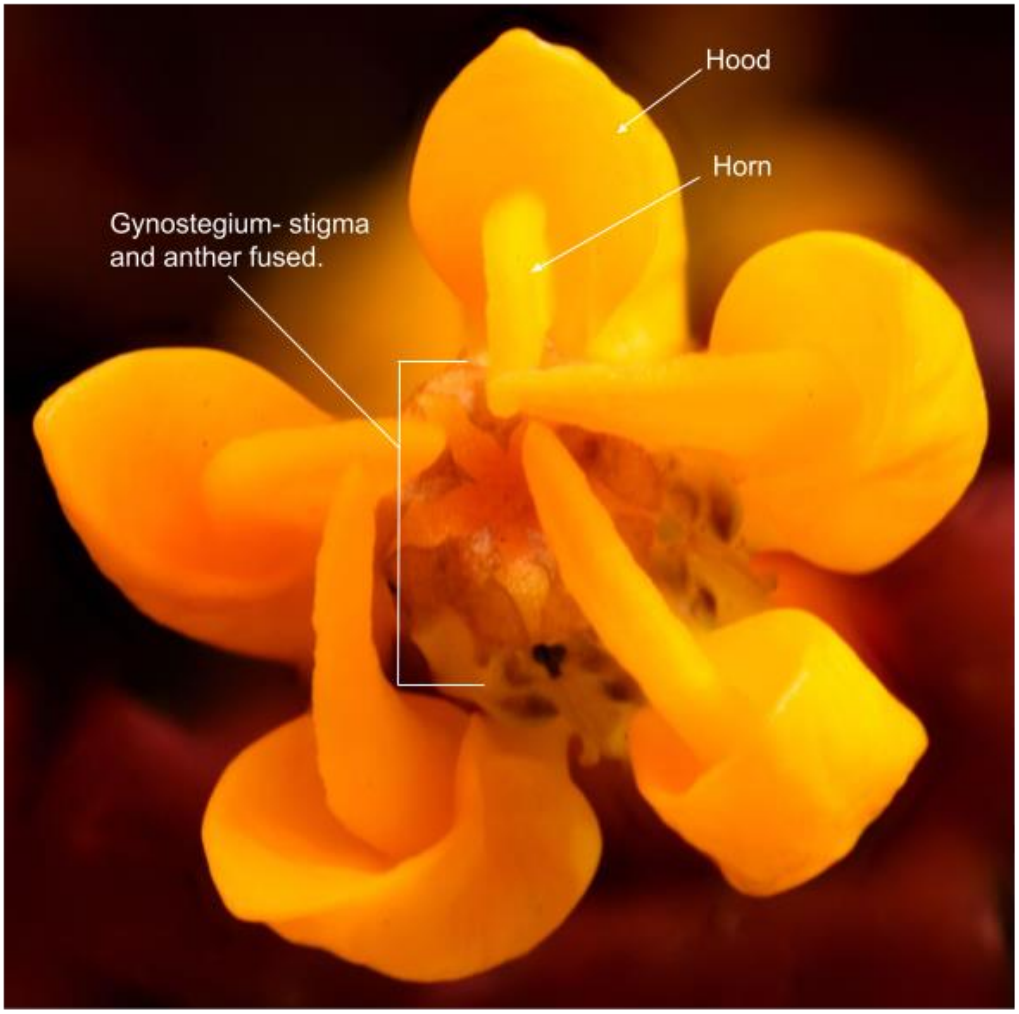


E. *Asclepias curassavica* (Tropical milkweed).

This flower consists of five structures called hoods that surround the middle of the flower. Each of these hoods have a horn that reaches toward the middle of the flower. The center portion is called the gynostegium, which consists of the stigma and anthers fused together. All of the male and female reproductive organs are located in the gynostegium. The *Asclepias curassavica* flower is pollinated by butterflies. See Figure 8b for labeled reproductive structures.

Figure 8a- *Asclepias curassavica* (Tropical milkweed).

Figure 8b- Labeled *Asclepias curassavica* (Tropical milkweed).



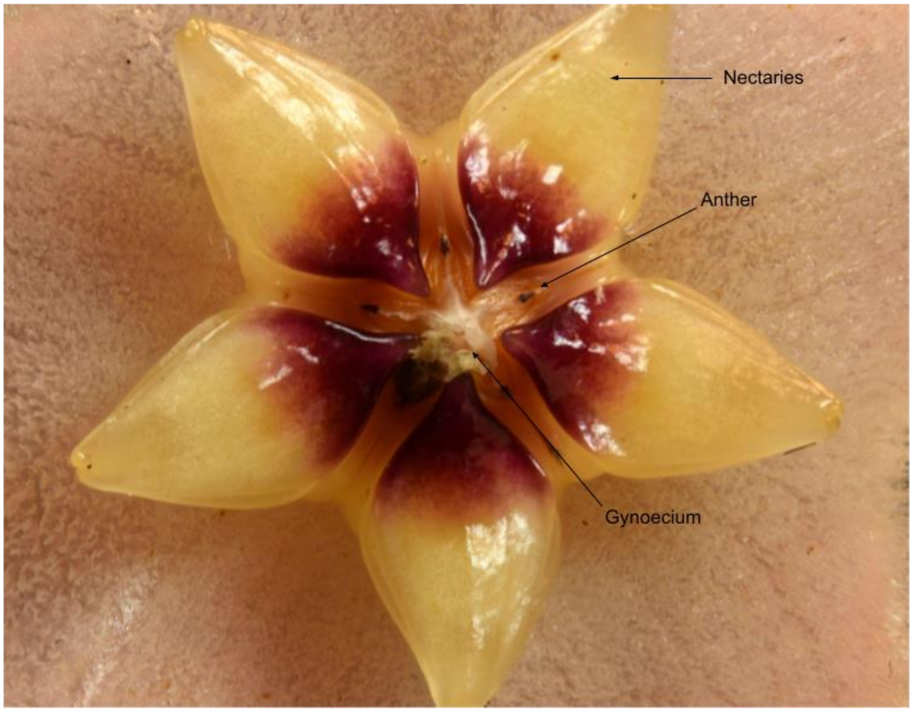
F. *Hoya carnosa* (Wax flower).

The *Hoya carnosa* flower has pink petals with a fuzzy appearance. The middle portion of the flower contains the nectaries, the anthers, and the gynoecium. The nectaries contain nectar that attracts the pollinator to the flower. The anthers are the small black portions in between the nectaries. The gynoecium is in the very center of the nectaries, containing the female reproductive structures. This flower is pollinated by medium or large moths. See Figure 9c for labeled reproductive structures.

Figure 9a- *Hoya carnosa* (Wax flower).

Figure 9b- *Hoya carnosa* (Wax flower).

Figure 9c- *Labeled Hoya carnosa* (Wax flower).



G. *Cestrum nocturnum* (Night scented jasmine).

The *Cestrum nocturnum* flower has a tubular structure with a pale color. Five pointed petals are at the opening of the tubular structure. The brown portions located at the opening of the tube are the anthers connected to the filaments. The female reproductive organs are located deep within the tubular structure of the flower, allowing pollinators with longer proboscises to pollinate this flower. The *Cestrum nocturnum* flower is pollinated by moths. See Figure 10b for labeled reproductive structures.

Figure 10a- *Cestrum nocturnum* (Night scented jasmine).

Figure 10b- Labeled *Cestrum nocturnum* (Night scented jasmine).

H. *Bougainvillea glabra* (Paper flower).

This flower has pink-modified bracts surrounding the small flower in the center. These brightly colored bracts attract the pollinator to the flower, and serve as a landing platform for non-hovering butterflies and moths. The small flower in the center has yellow-tinted petals encompassing the anther. More anthers with their filaments are located deeper in the tubular structure. The female reproductive organs, collectively called the gynoecium, are located deep in the tubular structure. The *Bougainvillea glabra* flower is pollinated by butterflies, moths, and hummingbirds. See Figure 11c for labeled reproductive structures.

Figure 11a- *Bougainvillea glabra* (Paper flower).

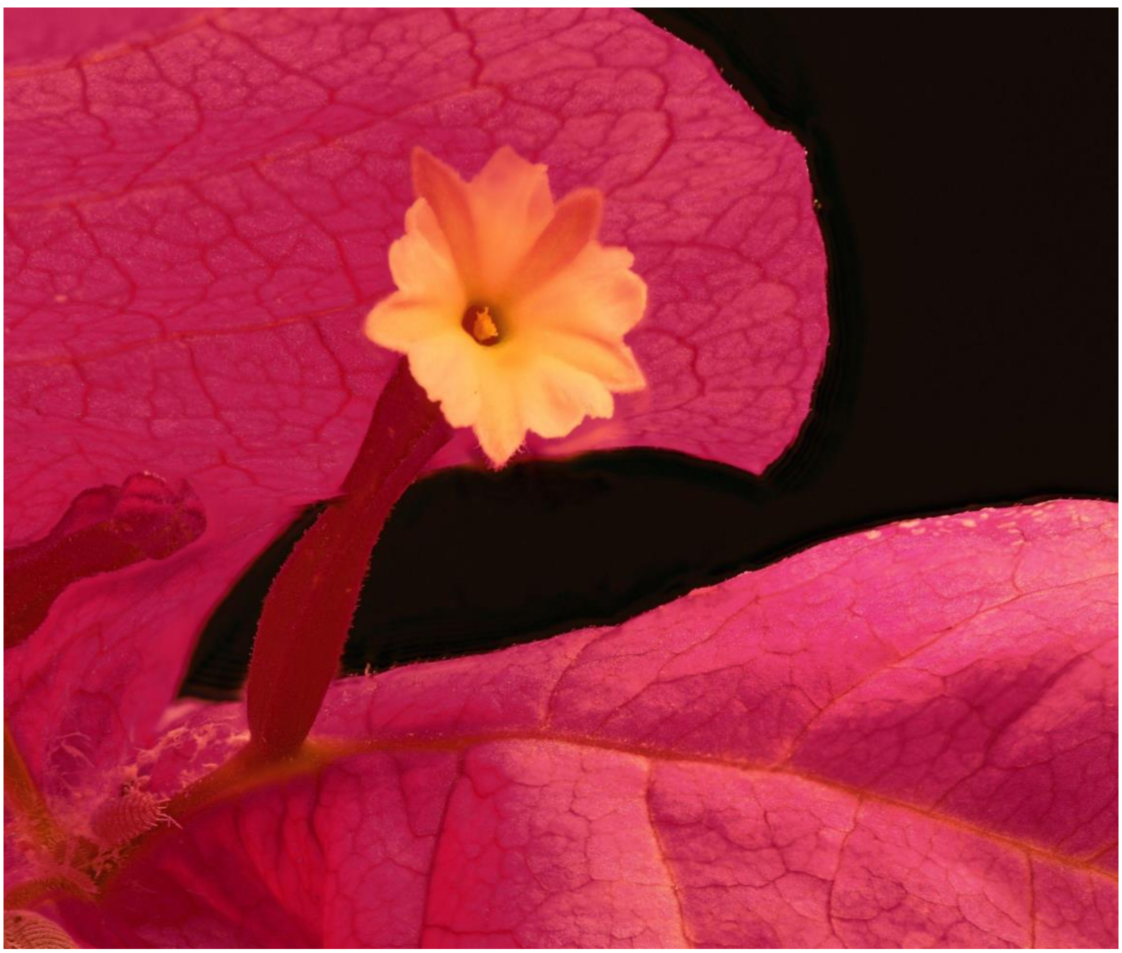
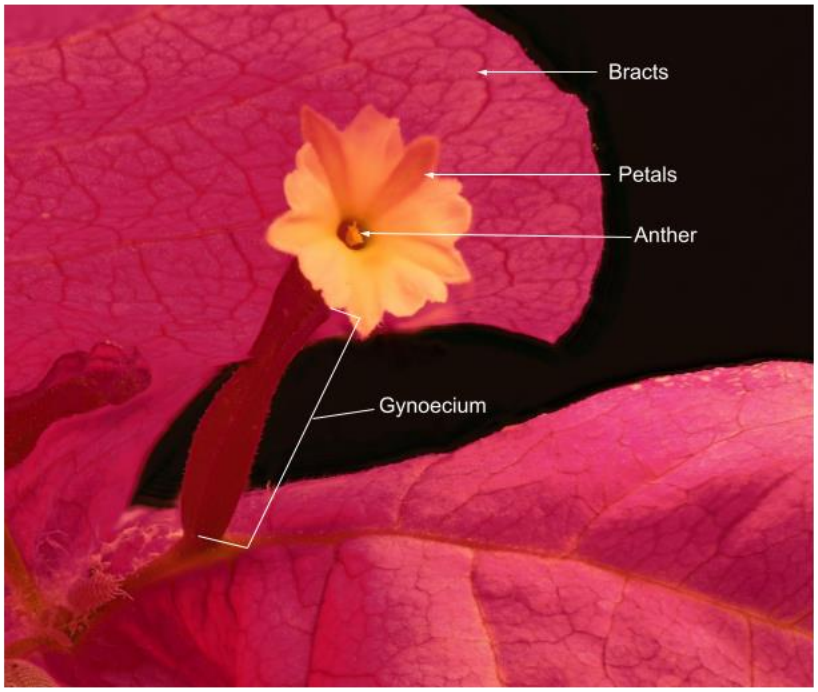


Figure 11b- *Bougainvillea glabra* (Paper flower).

Figure 11c- Labeled *Bougainvillea glabra* (Paper flower).



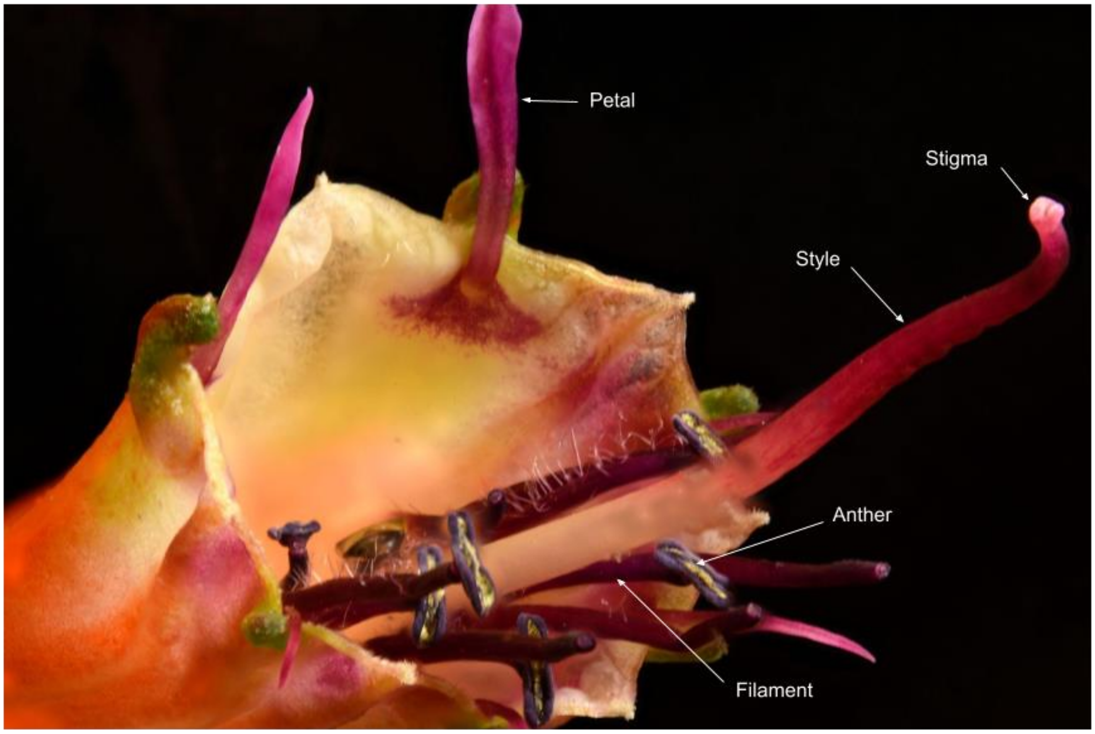
I. *Cuphea ignea* (Cigar plant).

The *Cuphea ignea* flower has a tubular structure with the stigma, style, anthers, and filaments protruding out from the opening of the flower. The style is long, with the stigma reaching away from the opening of the flower. The anthers with the filaments attached are located directly at the opening of the tubular structure. This flower is pollinated by butterflies and hummingbirds. See Figure 12c for labeled reproductive structures.

Figure 12a- *Cuphea ignea* (Cigar plant).

Figure 12b- *Cuphea ignea* (Cigar plant).

Figure 12c- Labeled *Cuphea ignea* (Cigar plant).



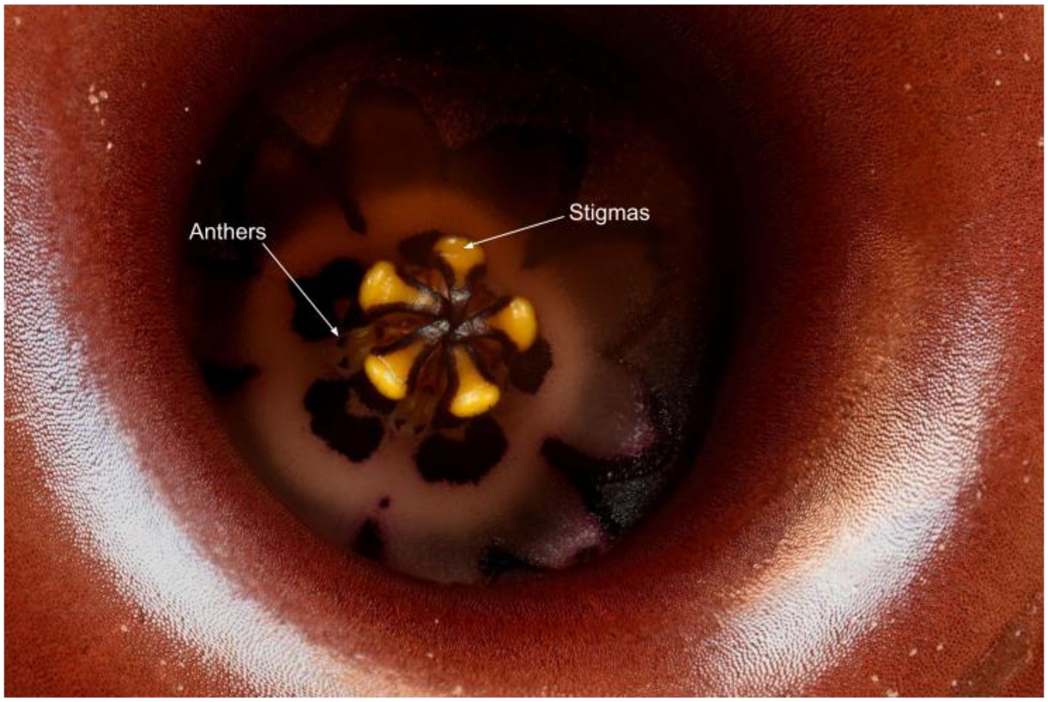
J. *Huernia zebrina* (LifeSaver Plant).

The *Huerina zebrina* flower is a type of star-shaped carrion flower. The reproductive structures are located deep inside the raised circular, red portion of the flower. There are five yellow, modified stigmas in the center of the flower, along with the small, black anthers located in between the modified stigmas. This flower is pollinated by flies and small wasps. See Figure 13c for labeled reproductive structures.

Figure 13a- *Huernia zebrina* (LifeSaver Plant).

Figure 13b- *Huernia Zebrina* (LifeSaver Plant).

Figure 13c- Labeled *Huernia Zebrina* (LifeSaver Plant).



K. *Frerea indica* (Leafy starfish).

The *Frerea indica* flower is a flat, open, and thin flower. The petals have a dark red and yellow appearance, which surrounds the gynoecium and the anthers in the center of the flower. The gynoecium is the white portion with a yellow tint, containing the female reproductive structures. The anthers are the brown/black structures located around and in between the gynoecium. This flower is pollinated by flies and small wasps. See Figure 14c for labeled reproductive structures.

Figure 14a- *Frerea indica* (Leafy starfish).

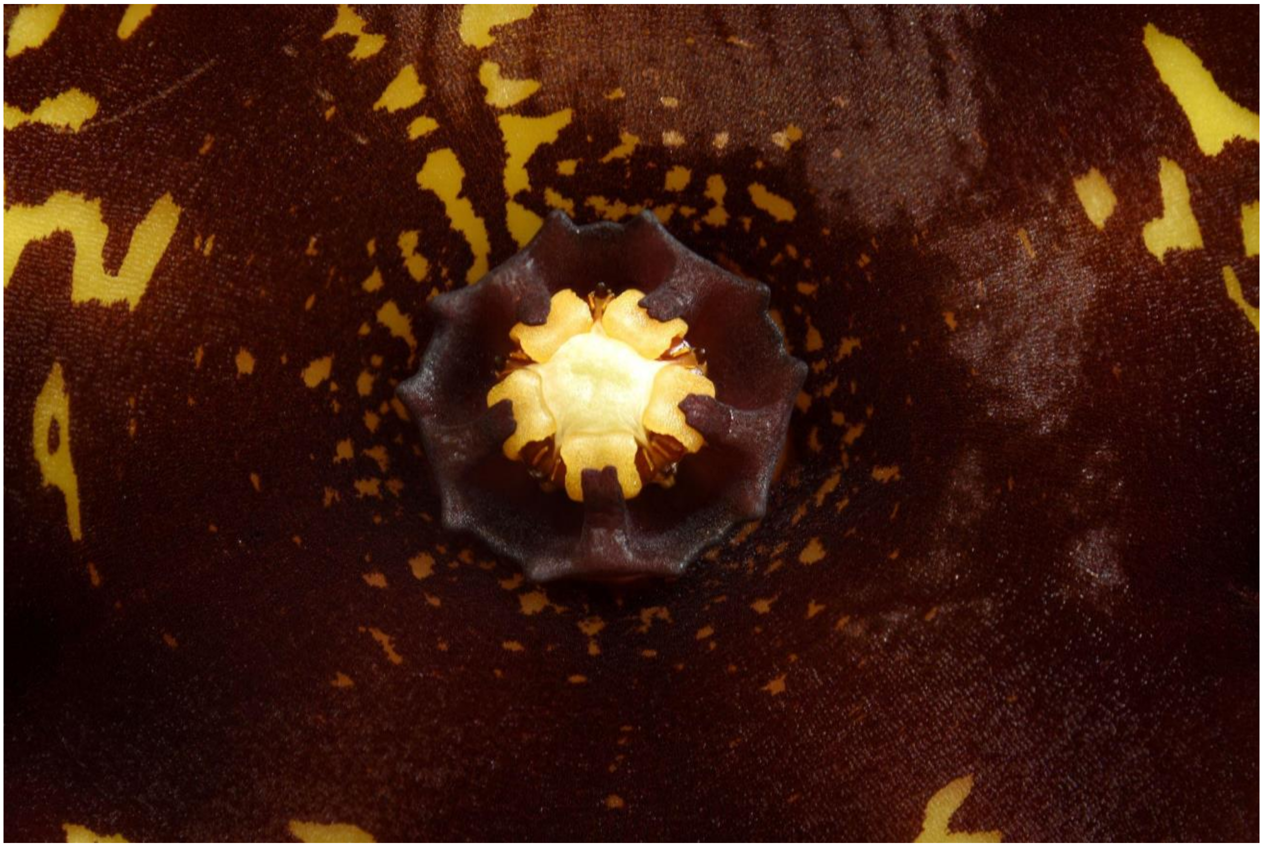


Figure 14b- *Frerea indica* (Leafy starfish).

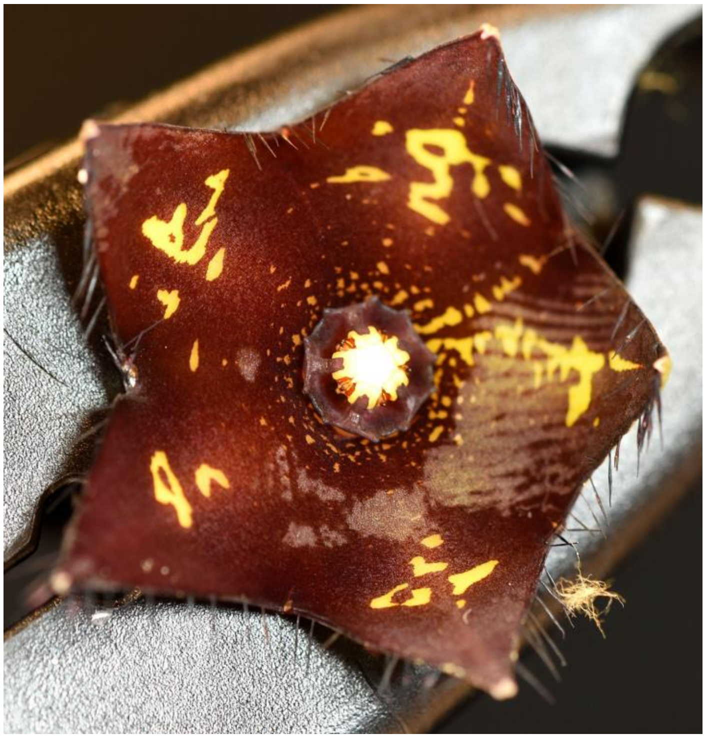
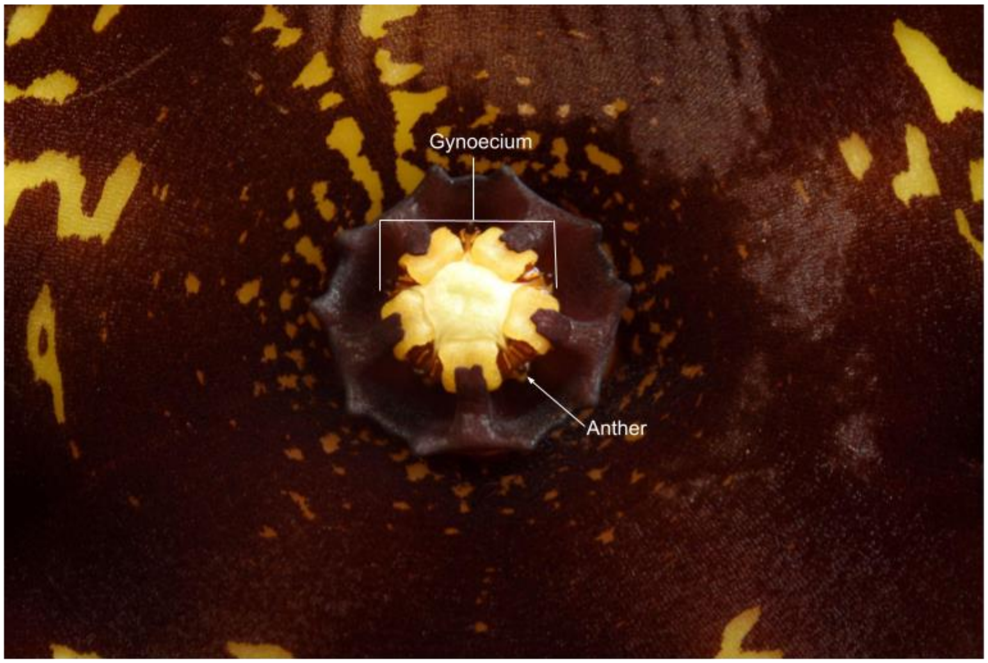


Figure 14c- Labeled *Frerea indica* (Leafy starfish).



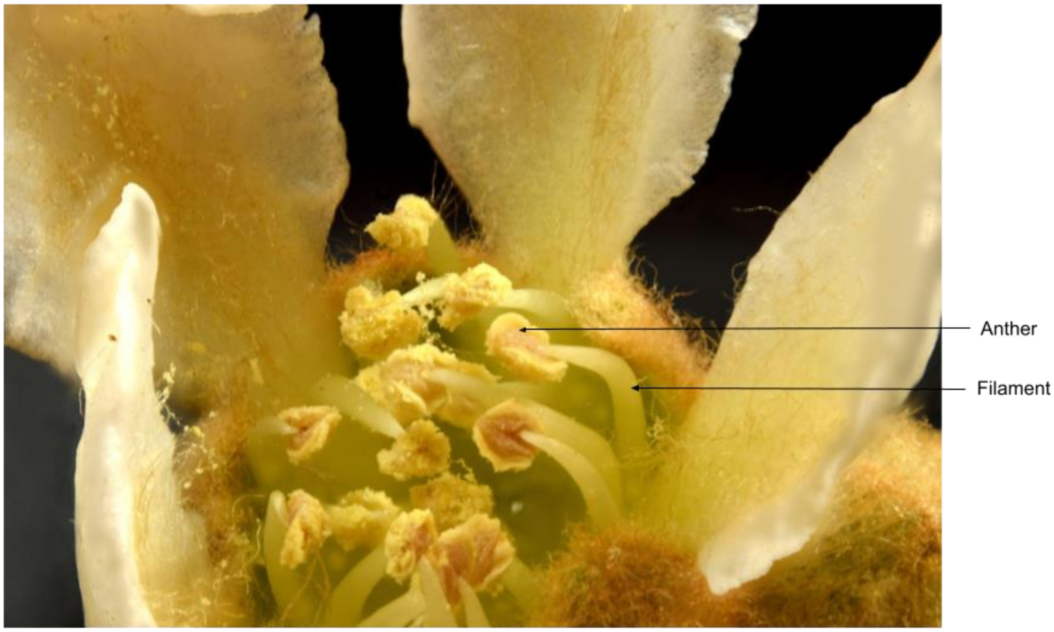
L. *Eriobotrya japonica* (Loquat).

This flower is characterized by white petals surrounding the reproductive structures. There are many visible anthers with filaments in the middle of the open layout of the flower. These anthers conceal the female reproductive structures, which are located below the anthers. The *Eriobotrya japonica* flower is pollinated by flies. See Figure 15c for labeled reproductive structures.

Figure 15a- *Eriobotrya japonica* (Loquat).

Figure 15b- *Eriobotrya japonica* (Loquat).

Figure 15c- Labeled *Eriobotrya japonica* (Loquat).



## DISCUSSION

The patterns and similarities found between the reproductive structures of the flower and the pollinator are a template for others to build on. In order to make concrete conclusions, thousands of flowers need to be photographed and analyzed. My results, and the discussion of these results, are the starting block for more researchers to make comparisons and conclusions. Although my research is a starting point, patterns were recognized for how various plants are specifically structured for the insect, bird, or mammal to pick up the pollen and carry it to the next plant.

A. Discussion of Flowers Pollinated by Bees.

From examining the flowers pollinated by bees, a landing platform is important, as bees do not typically hover in one place during pollination. This landing platform may be a petal, a certain reproductive structure, or a combination of structures on the flower. In addition to the flower having a landing platform, it needs to be located so that the bee's proboscis can reach the stigma. Landing platforms are observed in the *Clerodendrum ugandense, Vitex agnus, Plumbago auriculata,* and *Stanhopea oculata* flowers. In the *Clerodendrum ugandense* flower, the stamens, consisting of the filaments and anthers, may serve as a landing platform for their bee pollinator. This may be because there is too much space between the petals and the stigma and anthers, so the bee would be unable to reach the pollen and nectar if it landed on the petals. To obtain the nectar located at the base of the carpel, the bee would land on the stamens and brush past the anthers, picking up pollen that would be transported to the next flower. When the bee arrives at the next flower, it deposits the pollen on the stigma when feeding on the pollen and nectar. Stamens serving as a landing pad may be seen in the *Vitex agnus* flower as well. Based on observations of the *Vitex agnus* flower, there is not a petal specifically designed for landing, so it may be assumed that the stamens are the landing platform on this flower. The pollination strategy discussed above for the *Clerodendrum ugandense* flower would be similar for the *Vitex agnus* flower. A bee using a petal as a landing platform can be seen in the *Plumbago auriculata* flower. In the case of the *Plumbago auriculata* flower, the flat, open petals are close to the stigma and anthers so that pollination can take place. The *Stanhopea oculata* flower, on the other hand, has a very unique landing platform compared to the other flowers pollinated by bees in this research. This is due to the specific orchid bee pollinator the *Stanhopea oculata* flower requires. The platform is specifically designed for orchid bees to land on and reach the column containing the female reproductive structures. A landing platform is vital on flowers pollinated by bees, and this is observed in the *Clerodendrum ugandense, Plumbago auriculata, Vitex agnus,* and *Stanhopea oculata* flowers.

In addition to a landing platform, the stigma needs to be accessible to the bee's proboscis. The proboscises in the bees that pollinate the *Clerodendrum ugandense, Vitex agnus,* and *Plumbago auriculata* flowers are shorter than the proboscises in butterflies and moths. This means the stigma cannot be located deep within the flower because otherwise pollination would not occur. In these three flowers, the anthers and stigma are close to each other, allowing the bee to pick up pollen from the anthers, along with depositing the pollen on the stigma. The anthers and stigma are also located at the opening of the flower, enabling the bees to access these reproductive structures. The *Stanhopea oculata* flower, on the other hand, is pollinated by orchid bees, which have long, sucking proboscises. Orchid bees are able to reach their long tongues deep into the long column where the reproductive structures are located. This distinct arrangement of the reproductive structures allows the *Stanhopea oculata* flower to be pollinated by only orchid bees.

B. Discussion of Flowers Pollinated by Butterflies.

Some of the flowers photographed that are pollinated by bees are also pollinated by butterflies. These are the *Clerodendrum ugandense, Vitex agnus*, and *Plumbago auriculata* flowers. In addition to these three flowers, the *Asclepias curassavica, Bougainvillea glabra,* and *Cuphea ignea* flowers are also pollinated by butterflies. A landing platform is important for most flowers pollinated by butterflies to possess. Some butterflies are able to hover, but not always for long periods of time when drinking nectar. The landing platforms described for the *Clerodendrum ugandense, Vitex agnus*, and *Plumbago auriculata* flowers in the previous discussion of flowers pollinated by bees may be assumed to also serve as landing platforms for butterflies. The *Bougainvillea glabra* flower is unique in that it has a tubular structure where the reproductive organs are located, but the bracts may serve as a landing platform for butterflies.

In the case of the *Asclepias curassavica* flower, it can be predicted that the butterfly latches onto the bright orange hoods to feed at the nectar located deep within the gynoecium of the flower. Since the stigma and anthers are fused together in this flower, pollen may be picked up on the butterfly's face while the butterfly is feeding. As the butterfly arrives at the next flower, the pollen is deposited on the stigma while feeding on the nectar.

A characteristic of butterflies not seen in bees is the long length of their proboscises. Long proboscis allows butterflies to access the nectar deep within a flower. This means that the reproductive structures do not need to be located directly at the opening of the flower. A butterfly's long proboscis may allow pollination when the male, female, or both types of reproductive structures are located deeper within the flower. However, some of the flowers pollinated by butterflies that were photographed are also pollinated by bees. This means the reproductive structures are located towards the opening of the flower so that the bee's proboscis can reach them. Butterflies are able to pollinate flowers where the arrangement of the reproductive structures are also accessible to bees. The *Bougainvillea glabra* and *Cuphea ignea* flowers have a tubular structure where the nectar is located at the base of the tube. Also, some of the reproductive organs may be located deeper in the tube, such as the gynoecium in the *Bougainvillea glabra* flower. In addition to the location of the nectar and reproductive organs, most tubular flower structures do not have a landing platform, as seen in the *Cuphea ignea* flower. Because of these characteristics, this flower may be more designed for a hummingbird pollinator. The hovering capability of hummingbirds allows them to not need a landing platform while drinking the nectar. However, smaller butterflies with smaller wings may be capable of hovering and are most likely to be seen pollinating the *Cuphea ignea* flower.

C. Discussion of Flowers Pollinated by Moths.

The three flowers photographed that are pollinated by moths are the *Hoya carnosa*, *Cestrum nocturnum*, and *Bougainvillea glabra* flowers. These flowers all have very distinct structures from one another. The *Hoya carnosa* flower has a more flat and open structure, the *Cestrum nocturnum* flower has a tubular structure, and the *Bougainvillea glabra* flower has a tubular structure with bracts serving as a landing platform. This shows that one specific structure or one arrangement of reproductive parts is not required for moths to pollinate a flower. All moths are not the same, and different species of moths may require different arrangements of reproductive parts for pollination to occur. These different arrangements are seen very clearly in the *Hoya carnosa*, *Cestrum nocturnum*, and *Bougainvillea glabra* flowers.

The pollination strategy of the *Bougainvillea glabra* flower by butterflies, described in the previous section, is assumed to be the same strategy non-hovering moths use to pollinate the flower. The moths land on the bracts and insert their long proboscis deep into the tubular structure to feed on the nectar, in turn pollinating the flower. Different pollination strategies are seen in the *Hoya carnosa* and *Cestrum nocturnum* flowers.

The *Hoya carnosa* flower has a flat and open structure with the nectaries, anthers, and gynoecium being very accessible. This flower is unique in that it is specifically pollinated by the legs of medium or large moths. Although many moths can hover, some prefer to grip the flower with their legs while feeding on the nectar. Because of the different feeding habits of these moths that pollinate the *Hoya carnosa* flower, the structure of this flower is unique. While the moth is gripping onto the flower to drink the nectar, the pollen is picked up by its legs. When the moth arrives at the next flower, the pollen is deposited on the gynoecium as the moth holds onto the flower, while also picking up more pollen.

A different feeding habit than the one described above is seen in the *Cestrum nocturnum* flower, which has a tubular structure compared to the open structure seen in the *Hoya carnosa* flower. Because of the tubular structure, there is no landing platform, so hovering moths are the type of moth that pollinates this flower. Another unique characteristic of moths is their long proboscis. A long proboscis allows a pollinator to reach nectar concealed far at the bottom of a tubular structure of a flower. In the case of the *Cestrum nocturnum* flower, the moth hovers while inserting its proboscis deep within the flower. As the proboscis is inserted into the flower, it picks up pollen from the anthers located at the opening of the flower. Pollen is also picked up as the moth pulls out its proboscis from the flower. The pollen is then deposited on the next flower the moth feeds from. The arrangement of the anthers and stigma is specific for the feeding habits of certain moths, whether they are hovering moths or moths that prefer to land while feeding. The specific arrangement of the reproductive structures of the flowers pollinated by moths influences the species of moth that pollinates the flower.

In addition to moths' long proboscises, most moths are nocturnal, and most moths are able to hover, so flower structure and bloom time adapts to meet both of these characteristics. It is predicted that most moths active at night are hovering moths, meaning they pollinate flowers with tubular structures. This is specifically seen in the *Cestrum nocturnum* flower. The *Cestrum nocturnum* flower blooms at night where its pale-colored flowers reflect the moonlight, making it easier for moths to find their flowers from a distance. The flower also has a tubular structure, allowing hovering moths active at night to pollinate it. The connection between hovering moths active at night and a tubular flower structure is likely to be seen in other flowers as well.

D. Discussion of Flowers Pollinated by Hummingbirds.

The flowers photographed in this research that are pollinated by hummingbirds are the *Bougainvillea glabra* and *Cuphea ignea* flowers. These flowers both have a long tubular structure containing the reproductive organs. Hummingbirds have a long beak, enabling them to access the nectar at the base of the tubular structure. On the other hand, a pollinator like a bee does not have a long enough proboscis to reach the nectar, so they are prevented from pollinating flowers with long tubular structures. Most flowers with tubular structures do not have a landing platform, as seen in the *Cuphea ignea* flower. This means pollinators that do not need landing platforms, such as hummingbirds, are required for pollination of these flowers.

The positions of the anthers relative to the stigma are not the same in both of these flowers. In the *Cuphea ignea* flower, the stigma is located farther away from the entry of the flower containing the anthers. Since the stamens are close to the entry point of the flower where the hummingbird would insert its beak, it allows the pollen to be picked up by the face of the hummingbird. As the hummingbird arrives at the next *Cuphea ignea* flower, the pollen is first displaced at the stigma located farther from the entry of the flower. Then the hummingbird continues to insert its beak deep into the flower. In the *Bougainvillea glabra* flower, the anthers are located above the stigma, or closer to the entry of the flower. As the hummingbird inserts its beak into the flower to feed on the nectar, pollen is picked up from the anther. When the hummingbird visits the next flower, it is still able to displace the pollen on the stigma by sticking its beak into the flower. Since the positions of the anthers and stigma are not consistent between these two flowers, there must not need to be specific positions, heights, and lengths of the reproductive structures. Pollination still occurs whether the stigma or anthers are accessed first.

E. Discussion of Flowers Pollinated by Flies and Small Wasps.

Flies and small wasps are smaller insect pollinators than some of the pollinators described above, meaning the flower structures may be slightly different. Of the flowers researched, the *Huernia zebrina, Frerea indica,* and *Eriobotrya japonica* flowers are pollinated by flies and small wasps. These flowers all have a relatively flat and open structure, meaning the reproductive structures are not located deep within the flowers. This enables the flies and small wasps to crawl around and pick up the pollen. All of the reproductive structures are accessible for these pollinators to crawl around on, eliminating the need for hovering and long proboscises.

The *Huerina zebrina* flower has a raised, red portion that opens into the modified stigmas and anthers. The diameter of the raised, red portion is relatively small, preventing large insects from pollinating this flower. Although, flies and small wasps are still able to crawl into this opening to access the pollen. The *Frerea indica* flower is a very small, flat flower with both male and female reproductive structures located directly in the middle of the flower. The flies and small wasps are able to crawl around on both the anthers and the gynoecium, picking up pollen in addition to pollinating the flower. The *Eriobotrya japonica* flower has a slightly different structure than the *Heurina zebrina* and *Frerea indica* flowers, but it still has an open structure. The anthers are located directly at the opening of the flower, but the female reproductive parts are hidden beneath the anthers. Even though the gynoecium is partly hidden, the flies and small wasps are able to crawl around on the flower and pollinate it because of its open structure.

The specific arrangement of the anthers, stigmas, and other reproductive structures does not seem to hold much importance, as the positioning of the structures are not consistent between all three flowers I photographed. Flies and small wasps are able to pollinate these flowers whether some of the reproductive parts are partly hidden or completely out in the open. From my observations and research, the most important requirement for pollinators such as flies and small wasps are the open structures of the flowers. The gynoecium and androecium cannot be located deep within the flower, otherwise flies and small wasps are unable to pollinate the flower.

## CONCLUSIONS

The results found from my research are a template for other researchers to build on. In order to make concrete conclusions, thousands of flowers need to be photographed and analyzed. However, conclusions can be made from the twelve flowers I photographed.

Large, flying, non-hovering insects with variable lengths of proboscises require a landing platform. The arrangement of male and female reproductive organs is particular to the length of the insect’s proboscis. If the proboscis is long, then the reproductive organs may be located deep within a tubular structure, or towards the opening of the flower. In contrast, insects with short proboscises require the reproductive organs to be towards the opening, or surface, of the flower.

Hovering insects do not need a landing platform. Most hovering insects have a long proboscis, so the flower structure is most often tubular. The reproductive organs are located within the tubular structure where the long proboscis can reach.

Small, flying, non-hovering insects with short proboscises pollinate flowers with open structures. The arrangement of male and female reproductive organs is not as important, but placement of these organs is critical. The reproductive structures need to be accessible for the insects to crawl on, so they cannot be located deep within the flower.

These conclusions may be improved and more concrete if more methods were added to the research. If this research is done again, dissection of the flowers would provide better visualization and localization of the reproductive organs. This may provide additional information to the importance of the placement of the reproductive organs within a flower. Even though improvements can be made to my research, more of this work needs to be done in general. More flowers need to be photographed to find more correlations between the type of pollinator and specific flower structure. As more work is done, patterns that were not identified in my research may be recognized in further research.

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