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Pollination mechanisms and adaptations in flower and ornamental crops- A review

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Abstract
Pollination mechanisms and adaptation strategies pertaining to flower is a prerequisite for determining a successful flower breeding programme. Apart from knowledge regarding conventional breeding methodologies it provides necessary information regarding co-evolutionary process between plant and pollinators which is helpful further for conserving endangered ornamental plant species by protecting the plant specific pollinators. Plants and their pollinators form a mutualistic relationship, a relationship in which each benefits from the other. Though most of the flowers provides reward in form of pollen, scent, nectar etc. but deceptive systems can also be found among a diverse group of plants, the flowers of which signal the presence of a resource without providing it. Deceptive flowers have accordingly evolved the ability to emit signals that trigger obligate innate responses in the targeted insects. Floral thermogenesis being another typical adaptation strategy which plays a crucial role in pollination biology, especially in plant–pollinator interactions.

Key words: pollination, evolution, deceptive mechanism, thermogenesis.

Introduction
Pollination is one of the most fascinating processes in the world. Pollination is the process by which pollen grains are transferred from anthers to stigma. It is prerequisite for understanding coevolutionary processes between plants and their pollinators. This is also used for assessing threats from a potential pollination crisis. It has been found that Diptera can be highly important pollinators in some flowering plants (e.g. Ssymank *et al.,* 2008; Barraclough & Slotow 2010) [30, 5], and may also be important in the reproduction of certain threatened and endangered plants (e.g., Wiesenborn 2003; Murugan *et al.*, 2006; Humeau *et al.*, 2011) [35, 20, 13]. Pollination biology- provide theoretical framework for plant breeding and rearing pollinators. Plants and their pollinators form a mutualistic relationship, a relationship in which each benefits from the other. Plants provide rewards which is the main attractants for flower visiting insects and include pollen, nectar, essential oil etc. whereas advertisements are visual, chemical, or structural cues that provide information to potential pollinators about location of and access to floral rewards. Most species rely upon some kind of pollination vector to accomplish pollination (Endress, 1995). The vector can be any agent that can move pollen from anther to stigma *i.e* it may be biotic or abiotic vectors. Plants generally adopt adaptation strategies to assure pollination among which deceptive mechanism is one of the most interesting process. In this system flowers signals presence of rewards without providing it. These plants have thus evolved cues to cheat insects into the act of performing pollination. There are many ways by which insects can be duped and one of the most widespread adaptation is chemical mimicry. In this type of deception, odours often signal the presence of a mate (Ayasse *et al.*, 2003) [4], a prey (Di Giusto *et al.*, 2010) [9] or of a brood-site (Atwood, 1985) [3]. This review is about different mechanism of pollination and various adaptive strategies that plant follows in order to assure reproductive fitness.

What is pollination syndrome
Pollination syndrome is flower characteristics, or traits, that may appeal to a particular type of pollinator. Such characteristics can be used to predict the type of pollinator that will aid the flower in successful reproduction. A combination of color, odor, quantity of nectar, location and type of pollen, and flower structure can each affect a potential pollinator's ability to locate a flower and its food resources. Floral "pollination syndromes" (Faegri and Van der Pijl, 1979) [11] provide classical examples of convergent evolution — similarity of traits in unrelated organisms that have adapted to similar environmental factors. These syndromes, which arise when unrelated plants adapt to the same functional pollinator group (Fenster *et al.*, 2004) [12], are usually described using qualitative characteristics of the morphology, colour and scent of

flowers (Ollerton *et al.*, 2009) [21].

Pollination in flower is aided by either abiotic or biotic vectors

Pollination is facilitated by involvement of either biotic or abiotic vectors. Biotic vector refers to the involvement of animals helping in pollination whereas abiotic pollination refers to pollination mediated without the involvement of animals, but excluding self-pollination. Anemophily (pollination by wind) and hydrophily (pollination by water) are the two principal forms of abiotic pollination and occur in approx. 20 % of angiosperm families (Ackerman, 2000) [1]. However another unusual method of pollination mechanism is prevalent in windswept and rainy areas where pollination is mediated by rain splashe s (ombrophily – Daumann, 1970) [8]. Such rain-mediated pollination mechanisms have generally been regarded as strategies for reproductive assurance functioning to promote self-pollination under adverse conditions when pollinators are infrequent (Fægri and van der Pijl, 1979) [11].

Vector/Pollinator	Nomenclature for pollination type	Flower/ornamental crop
Biotic Vector		
Bees	Melittophily	Begonia
Butterflies	Psychophily	Orchid
Moths	Phalaenophily	Datura
Flies	Myophily	Primrose
Carrion flies	Sapromyophily	Dead Horse Arum Lily
Beetles	Canthorophily	Magnolia, Water Lily
Birds	Ornitophily	Bird of Paradise
Bats	Chiropterophily	Agave, African Baobab
Abiotic vector		
Air movement	Anemophilous	Rhododendron, Azalea, Acacia
Water movement (Hydrophilous)	Hydrophilous	*Salix alba, Euphorbia grantii*
Rain Pollination	Ombrophily	*Acampe rigida*

Flowers adaptations related to pollination syndromes

Shape

Flowers are shaped principally through natural selection by their pollinators. Flower shapes vary according to flowering plants and also as a result of convergent evolution. An example would be a flower form attractive to hummingbirds. The flowers would share a red-orange color, a long floral tube shape, a sweet fragrance and a nectar reward at the base of the floral tube. This group of unrelated plant species that benefit each other is called as plant guild. Flowers adapted to bee pollination often have colored guides on a landing platform formed by the lower petal. The nectar is located at the base of the tubular flower often requires the bee to enter the flower. Some flowers adapted for butterfly, moth or hummingbird pollination take advantage of the insect's long mouth parts and produce nectar in spurs at the base of the flower.

Fragrance

Flower scent is a major pollinator attractant. Mostly flowers which opens up at night are pleasantly fragrant that guide the pollinators aiding in pollination and providing them fragrance reward and sometimes essential oil also. Some of the flowers are Jasmine, tuberose, Night Jasmine etc.

Food rewards

Flowers used to provide nectar, oil, pollen etc as food reward to the pollinators. Nectar glands are often produced at the base of long tubular flowers. These flowers may be adapted for pollination by insects or birds with long mouth parts. The male stamens and female stigma are located at the mouth of the flower where they will come into contact with the visiting pollinator. Bumble bees (Bombus) can be seen "stealing" nectar from sage and four o'clock flowers. Both flowers have long, narrow floral tubes that would restrict access for bees so they resort to going directly to the nectar source. In some Caesalpinoid legumes like royal Poinciana (Delonix), the upper flag petal has color nectar guides for pollinators. As the flower ages, the flag petal folds over making it no longer visible as a nectar guide.

Energy

Floral thermogenesis plays a key role in pollination biology- particularly plant pollinator interactions. Flowers of thermogenic plants have the ability to maintain a relatively higher temperature than ambient environments during anthesis to maintain an optimal microclimate within flowers (Li, 2009) [16]. In some plants, flowers possess dense pubescence and overlapping bracts to minimize heat loss and protect their flowers from cold (Meinzer and Goldstein, 1985; Miller, 1986; Tsukaya *et al.*, 2002) [17, 19, 32]. This floral heat can serve as energy reward to the pollinators and in turn flowers can get successfully pollinated. This kind of adaptive strategy can be found in Two types of thermogenesis have been identified among thermogenic plants. In some species independently of ambient temperature floral temperature is maintained at a constant range, throughout anthesis. These are thermoregulatory species, such as *Philodendron selloum* (Seymour, 1997) [25], *Nelumbo nucifera* (Seymour, 1998) [24] and *Symplocarpus foetidus* (Seymour, 2004) [27]. In other thermogenic species, heat production usually corresponds to the period when female flower parts are most receptive to pollination and when floral scents are strongest such as in *Dracunculus vulgaris*, *Helicodiceros muscivorus* (Seymour, 2003) [23] and Magnolia species (Wang, 2012) [33]. Such thermogenic plants are sometimes referred to as pseudo-thermoregulatory species. Thermogenesis directly rewards pollinators with energy, especially at night when no floral scents are released (Seymour, 1997) [25].

Colour

Flower colours act as sensory signals that attract pollinators by 'advertising' the quality and quantity of floral rewards (Melendez *et al.*, 1997; Aragon *et al.*, 2004) [18, 2]. Flower colour differs among flowering plants and also changes with flower life. These colour variations are not referred to the darkening or fading of floral senescence, but to changes in fully blooming turgid flowers (Weiss 1995) [34]. The flowers in Japanese honeysuckle are red in bud, opening to white then changing to yellow. The colours are acting as colour signals to pollinators to indicate which flowers to visit for the sweetest nectar reward. Floral colour change is visual cues for pollinators to avoid old flowers and increase pollination efficiency. *Quisqualis indica* flowers change colour from white to pink to red which may be associated with a shift from moth to butterfly pollination. Flowers initially open white and are pollinated by hawk moths. As the flowers change to pink and then red, they hang down and are pollinated by other insects like bees and flies (Yan *et al.*, 2016) [14].

Pollination specialists

Pollination in some plants is highly specialized. In the orchids and Asclepiads like Hoya and milkweed (Asclepias), pollen is produced in specialized packets called pollinia. Pollinium are specialized packets of solid pollen that must be extracted from the flower by the insect pollinator and are specifically deposited on the stigma when they visit the next flower. The female and male organs in orchid flowers are also fused into a gynostegium called a column. The pollinia must be removed from the anther cap by an insect and redeposited on the open sticky stigma usually located just under the anther cap on the column.

Mimicry

It is a Common Pollination strategy. In this type of adaptation, flowers do not offer any pollination reward (such as pollen or nectar), but deceptively entices the pollinator into visiting the flower. This kind of phenomena is well known in the Orchidaceae, -one-third of the species (Renner, 2006) [22].

Different pollinators in some orchid species

Name	Pollinators	Remarks
Acianthera johannensis, Acianthera fabiobarrosii	Females of the genera *Tricimba*	Mimics smell of fish and no nectar production
Acianthera adamantinensis	Flies	Dog feces odor
Pleurothallis marthae	Fungus gnats	Fungus like odor and lightly sweet nectar at night time
Bulbophyllum phalaenopsis	Flies	Mimics rotting flesh with maggots
Geoblasta pennicillata	Scoliid wasp	Pseudocopulation

Basic types of mimicry and deceit

- Mimicry of another plant species that offers a food reward
- Mimicry involving imitation of a floral part to attract pollinators to a food reward
- Physical imitation of an insect
- Brood site mimicry
- Floral traps

Mimicry of another plant species

The most common form of food reward mimicry involves imitation of the floral features of a reward species. Floral features successfully imitated include color spectrum, shape and form, and scent.

Mimicry involving imitation of a floral part

There are numerous examples of mimicry that involves the imitation of floral parts within a single flower or flower-to-flower. In begonia, only male flowers offer a pollen reward. To invite visitation to the female flower, the twisted styles and stigmas have the appearance of the male stamens. This is sometimes referred to as floral automimicry. Pseudostamens are markings on the petals that resemble anthers usually as a bright yellow spot on the petals. Flowers with pseudostamens often offer a nectar reward. Heteroanthy is when stamens within the same flower have different morphologies as seen in crapemyrtle (Lagestroemia). The inner whorl of stamens are on short filaments and grouped in the centre of the flower. The outer whorl of stamens is on long, pigmented filaments and act as a signal to attract pollinators.

Physical imitation of an insect

The flowers in the orchid species, Ophrys, resembles a bee in shape and coloration. The strategy is to attract male bees seeking female bee companionship (pseudocopulation). The simulated mating moves pollinium from one flower to another. It is estimated that over 1,000 species of orchids employ forms of sexual deceit. Sexual mimicry is most common in Orchid genera (Dressler 1981; Williams & Whitten 1983; Singer 2002) [10, 36, 26].

Brood site mimicry

Brood site mimicry is a peculiar type of reproductive deception where the flower mimics a site, which insects mistake for a place to deposit eggs. A common feature of brood site flowers is the production of a fetid odor to attract carrion flies (sapromyophily) or dung beetles (coprocantharophily). *Rafflesia arnoldii* produces the world's largest single flower (up to 3 feet across) and it produces a fetid, rotting flesh odor to attract pollinators (Seymour, 2010) [28]. Visual signals plays important role in pollinator attractions as bigger size represents more odour producing organs and amount of produced odur in order to attract insects is positively correlated. This kind of mimicry is strongly signified by the presence of distinct oligosulfides (dimethyl mono-, di and trisulfides). However, other compounds can be found (often at lower amount) such as monoterpens, long chain organic acid and benzenoids (Borg Karlson *et al.*, 1994; Burger *et al.*, 1988; Kite and Hetterschieid, 1997) [6, 7, 15]. These substances have been shown to be crucial cues for blowflies (Calliphora and Lucilia), as they are used as key odors to locate carrion resources (Stensmyr *et al.*, 2002) [31].

Floral traps

The diurnal types of Nymphaea, the flowers open and attract beetles, flies or bees. There is a stigmatic fluid that fills the floral cup. Visiting insects (especially flies and bees) fall into the cup and eventually drown. The fluid washes off any pollen on visiting the insects to pollinate the plants.

Conclusion

Further research work on pollination mechanisms on potential underexploited and endangered ornamental plant species is need of the hour to facilitate breeding programme and conservation of those plants. With the decline in both wild and domestic pollinators due to indiscriminate use of pesticide, environmental pollution etc. pollination management is becoming increasingly important issue in horticulture sector. Therefore focus should be given in this arena to conserve plant specific pollinators to prevent them from extinction. Pollination Management accomplish or enhance pollination of a crop, to improve yield or quality, by understanding of the particular crop's pollination needs, and by knowledgeable management of pollenizers, pollinators, and pollination conditions.

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