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Pollination Biology of Major Species of Piperaceae Family

***Pooja S.*[1] *and Vijaykumar B. Narayanapur**[*2]

[1]*Research Scholar, Department of Plantation, Spices, Medicinal and Aromatic Crops, College of Horticulture, UHS, Bagalkot, (Karnataka), India.*
[2]*Assistant Professor and Head, Department of Plantation, Spices, Medicinal and Aromatic Crops, College of Horticulture, UHS, Bagalkot, (Karnataka), India.*

(Corresponding author: V.B. Narayanapur)*
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ABSTRACT: The Flowering plants and their animal pollinators are important components of both natural and agrosystems, and they provide many fascinating instances of ecology and evolution in action. Piper's reproductive traits, such as short spike inflorescences with hundreds of reduced flowers, make it easy to identify. Piper has been reported in 100 species, with the majority of them found in the Western Ghats and Eastern Himalaya, with about 65 species found in the northeastern states. The majority of the species studied were dichogamous, with pollen release and stigma receptivity separated by time within the flower. The androecium develops bilaterally in Piper flowers, with stamens beginning in pairs or individuals, according to research. The flower is perianthless and protected by a bract, with a creamy colour. In Piperaceae inflorescences, Coleoptera and Hemiptera species were also detected, but they rarely migrated between flowers and acted as herbivores, devouring and sucking flowers and fruits. The pollination process exemplifies the value of biodiversity, demonstrating how each organism, insect, and animal contributes to the ecosystem. Pollination is responsible for a wide range of food, primarily horticulture crops, that we consume. Animal pollination benefits three-quarters of all crops in some way. It's uncertain how decreased biodiversity will disrupt ecosystem dynamics if animal extinctions continue at a pace of one per 16 years. Pollination biology in India started mostly as a descriptive science aiming at understanding plant morphology and anatomy in relation to pollination. Thus, The floral morphology and phenology is essential to understand the pollination biology of the plant.

Keywords: Piper, Pollination, Angiosperms, Piperaceae, Dioecious.

INTRODUCTION

The interactions between flowering plants and their animal pollinators are responsible for the enormous diversity of angiosperms, which now number 350000 species (Nepokroeff, 2011). Early spermatophytes (seed plants) relied heavily on the wind to transport pollen from one plant to the next, and it wasn't until around 125 to 115 million years ago that a new pollination technique emerged, and angiosperms (flowering plants) first arose (Dar, 2017).

Pollination by animals was responsible for the sexual reproduction of about 90% of current angiosperm species (Kearns *et al.,* 1998). Pollination is essential for food production and human survival, and it connects wild ecosystems and agricultural production systems. The Vth Conference of Parties to the Convention on Biological Diversity (CBD) established the International Project for Pollinator Conservation and Sustainable Use as a cross-cutting initiative within its work on agricultural biodiversity. As a result, flowering plants and their animal pollinators play an important role in both natural ecosystems and agrosystems, and provide a wealth of fascinating examples of ecology and evolution in action. Pollination biology knowledge is so widely applicable, with applications in ecology, evolutionary biology, conservation, entomology, and horticulture.

Spices in India

India is recognized as the spice capital of the world, and Indian spices are prized for their incomparable scent, texture, and flavour. India is the world's largest spice producer, user, and exporter. During 2020-21, India production with 1,04,85,100 tons of spices and its spice products are produced from an area of 45,17,720 hectares (Spices Board, 2001-2021). Black pepper is the world’s most commonly used spice, is the best-known member of Piperaceae and Piperaceae is commonly known as the pepper family.

Scientific classification of genus *Piper*

According to APG IV (2016) classification, the clade magnoliids stand in between basal angiosperm and the monocots. Magnoliids has most features of the early angiosperms. Classification of genus Piper was given by Kunth (1839) followed by modification by Decondelle (1923). Trelease and Yuncker (1950), Burger (1971), APG I (1998), APG II (2003), APG III (2009) and APG IV (2016).

In order Piparales, Piperaceae is the largest family which is pantropical and includes 5 genera namely *Piper* (Linnaeus, 1753), *Peperomia* (Ruiz and Pavon, 1794), *Zippelia* (Blume, 1830), *Verhuellia* (Miquel, 1843) and *Manekia* (Trelease, 1927). The economically important species of the genus *Piper* includes *Piper nigrum* L., *Piper longum* L., *Piper betle* L., *Piper cubeba* L. and *Piper chaba* Hunter.

Phylogeny of genus *Piper*

According to Abril *et al.* (2006), phylogenetic research revealed that the genus Piper represented three major geographical regions: America (1300 species), Asia (600 species), and the South Pacific (600 species) (100 spp). Over 100 species of Piper have been identified in India, with the majority of them found in the Western Ghats and Eastern Himalaya, with about 65 species in the north-eastern provinces (Jaramillo and Manos, 2001).

Table 1: Economically important species.

True pepper- Black pepper	*Piper nigrum* L.
Long pepper-Indian long pepper	*Piper longum* L.
Betel vine	*Piper betle* L.
Java long pepper	*Piper chaba* Hunter
Tailed pepper	*Piper cubeba* L.
Wild pepper	*Piper mullesua*
Helmet pepper	*Piper galeatum*
Wild betel	*Piper hymenophyllum*
Other species	*Piper attenuatum*
	Piper wightii

Ravindran (2006)

Floral diversity and breeding system of genus *Piper.*

Piper reproductive traits, such as short spike inflorescences with hundreds of reduced flowers, make it easy to identify. Piper species from Africa are monoecious or dioecious, hermaphrodite in the neotropics (Yuncker 1978), and dioecious in Asia and the South Pacific (Jaramillo and Manos, 2001). *Piper gaudichaudian* was found to be unisexual in neotropical *Piper arboretum,* as well as bisexual in andromonoecious populations from South Eastern Brazil (Figueiredo and Sazima, 2000; Silva and Vieira, 2015). The perianthless bloom is protected by a bract, and the flower colour is creamy, yellowish, or whitish (Figuerido and Sazima, 2000) and pink and violet (Tebbs, 1989). Inflorescence is spike or catkin (Suwanphakdee *et al,* 2006). The androecium has one to ten stamens, whereas the gynoecium has three to four stigmata (Jaramillo and and Manos, 2001).

Most studied species were described as dichogamous with pollen release and stigma receptivity temporally isolated within the flower. Complete or incomplete protogyny (Martin and Gregory, 1962; Figueiredo and Sazima, 2000) and incomplete protandry (Figueiredo and Sazima 2000; Kikuchi *et al*., 2007) are recorded. Both self-compatibility (Figueiredo and Sazima, 2000), as well as self-incompatibility (Figueiredo and Sazima, 2000; Kikuchi *et al*., 2007) have been reported in the genus.

Burger (1971) observed a shift in anther dehiscence from a lateral slit to an upwards or apical opening in flowers of densely packed inflorescences. The androecium develops bilaterally in Piper flowers, with stamens beginning in pairs or individuals, according to research (Tucker, 1982).

At two semideciduous forest sites in South Eastern Brazil, the phenology, floral biology, and breeding system of 14 Piperaceae species were reported. Five of them had a high level of self-compatibility, and one of them was andromonoecious. Seven of the species were pollinated by the wind, whereas three were pollinated solely by insects. Hover flies and bees were the most common flower visitors (Figueiredo and Sazima, 2000). Piper plants in Central America were mostly pollinated by stingless bees of the genus Trigona. Flowering took place throughout the year, with a peak during the windy months. Insects visited the odorous and nectarless blooms of all species (Semple, 1974; Fleming, 1985). Pollen is sought by hoverflies and bees at Piperaceae blooms. Flies touch the open anthers with the labell as they go along the inflorescence.

Pollination activity was investigated for *Piper glabrescens, Piper hispidum, Piper jacquemontianum*, and *Piper umbellatum*, common species in the Rio Abajo Forest Preserve in Puerto Rico. During observation periods, the main floral visitors were syrphid and drosophilid flies, which suggests they play a prominent role as potential pollen vectors for these four species. In addition, two ant species (*Linepithema iniquum* and *Wasmannia auropunctata*) were observed to nest in the stems of three Piper species (*Piper abajoense, Piper aduncum*, and *Piper umbellatum*). In the case of *Piper umbellatum*, this interaction is the first documentation of an ant-plant association in Piper section Pothomorphe (Wisniewski *et al*., 2019).

Hoverflies contact the bracts with their labells in certain cases, likely collecting pollen grains or some other substance. The bees capture pollen with their legs as they go faster along the inflorescence. Flies visit multiple inflorescences before leaving the plant, whereas bees only visit two to four, both travelling from the proximal to the distal section of the inflorescence. In Piperaceae inflorescences, Coleoptera and Hemiptera species were also detected, but they rarely migrated between flowers and acted as herbivores, devouring and sucking flowers and fruits. Spiders belonging to the Thomisidae family prey on bees and flies that visit the inflorescences of *Piper crassinervium* and *Piper regnelli* (Figueiredo and Sazima, 2000). Several ant species have been noted to inhabit Piper spp. (Muñoz *et al*. 2012)

Floral Biology and Breeding System in Black Pepper

Scientific classification of the genus *Piper*

- Kingdom: Plantae
- Clade: Angiosperms
- Clade: Magnoliids
- Order: Piperales
- Family: Piperaceae
- Genus: *Piper*
- Species: *nigrum*

Floral biology of *Piper nigrum* L.

Pepper is mostly dioecious in wild form (CSIR, 1969), but in the cultivated types, the plants are mostly gynomonoecious (i.e., bearing female and bisexual flowers) or trimonoecious (i.e., bearing female, male and bisexual flowers).

Table 2: Sexual composition of flowers of some pepper varieties and cultivars.

Varieties	Bisexual flowers %	Female flowers%	Male flowers %
Panchami	95.50	4	0.50
Panniyur 1	99.20	0.07	0.01
Panniyur 2	96.70	3.3	0
Panniyur 3	99.90	0.10	0
Panniyur 4	96.40	3.60	0.50
Pournami	84	15	1
Subhakara	99	0.50	0.50
Sreekara	98	1	1

Ravindran (2006)

Cultivars	Bisexual flowers%	Female flowers %	Male flowers %
Aimpirian	96.39	0.45	3.16
Bilimalligesara	93.69	5.75	0.56
Cheriyakanniakadan	1.64	98.36	0
Jeerakamundi	86.83	11.76	1.41
Kalluvally	78.56	21.44	0
Karimunda	94.25	0	5.73
Kottanadan	99.49	0.21	0.30
Kuthiravally	88.58	10.56	0.77
Malamundi	86.04	13.61	0.35
Manjamundi	36	63.49	0.51
Narayakodi	46.65	53.35	0
Neelamundi	99.02	0.87	0.11
Pereambramunda	19.64	79.66	0.36
Thevamundi	96.14	2.48	1.38
Vadakkan	98.49	1.27	0.24

Ravindran (2006)

Descriptors for Black pepper has been put forward by Bioversity International (1995) in which different spikes form are described as follows

1. Spike orientation: Erect and Postrate

2. Spike shape: Filiform**,** Cylindrical**,** Globular**,** Conical

3. Bract type: Sessile oblong and adnate to the rachis**,** peltate orbicular**,** copular with decurrent base**,** fleshy, connate, transformed into a cup**,** deeply copular with decurrent base.

Table 3: Floral characters of *Piper nigrum* L.

Sr. No.	Characters	References
1.	**Inflorescence**	Spike: Filiform, pendulous, young ones green or whitish green, mature ones green or pale yellow
2.	**Flower colour**	Creamy, yellowish or whitish
3.	**Spike colour**	Young -green or whitish green, Mature- green or pale yellow

4.	**Peduncle**	Glabrous
5.	**Bracts**	Oblong, sessile, shallow cups in female spikes.
6.	**Stamens**	2
7.	**Anther**	Dithecous
8.	**Carpel**	Single
9.	**Ovary**	Spherical(single)
10.	**Style**	Absent
11.	**Stigma**	3-5 lobed,pappilate
12.	**Fruit**	Drupe (green to red on ripening)
13.	**Seed**	Spherical and pungent

(Ravindran, 2006)

Bisexual flowers are protogynous and stigmata are exerted 3-8 days before anther dehiscence. Stigmata remain receptive for ten days with peak receptivity 3-5 days after exertion (Martin and Gregory, 1962*).*

Table 4: Studies on anthesis, anther, stigma and pollen of *Piper nigrum* L.

Sr. No.	Floral characters	Description	Reference
1.	**Anthesis**	18-00-18.30 h	Nybe *et al*., (2007
	Anthesis	4.00pm	Ravindran, (2006
	Anthesis– peak opening	19.30-20.30 h	Kanakamony, 1982.
2.	**Anthesis type**	Acropetal	Ravindran, (2006)
3.	**Anther dehiscence – (Sarawak)**	12.00-14.00 h	Warrd and Zevan, (1969)
	Anther dehiscence	14.30-15.30 h	Nybe *et al*., (2007)
	Anther dehiscence	11.00 pm to 12.00 pm.	Chen *et al*., (2018)
4.	**Stigma receptivity**	3-5 days after flower Opening	Purseglove, (1968)
	Stigma receptivity	10 days after flower opening	Kalinganire *et al*., (2000)
	Stigma receptivity	7 days after flower opening	Nybe *et al*., (2007)
	Stigma receptivity- peak	3-5 days after flower opening	Chen *et al*., (2018)
5.	**Pollen along equatorial Axis**	9.5-13.0 µm	Rahiman, (1981)
	Pollen along polar axis	7.0-10.5 µm	Rahiman, (1981)
	Pollen grain mean Diameter	9.86µm	Nybe *et al*., (2007)
6.	**Pollen structure**	Monosulcate, non-aperture or porate	Rahiman, (1981)
	Pollen structure	Spherical shaped, radially symmetrical and with irregular pinulose sculpturing.	Chen *et al*., (2018)
7.	**Pollen size**	10 µm	Martin and Gregory (1962)
	Pollen size (cv. Semongok Aman)	<10µm	Chen *et al*., (2018)
8.	**Pollen production/anther**	100,000-300,0000	Martin and Gregory (1962)
	Pollen production/flower	7000-13000	Nybe *et al*., (2007)
9.	**Pollen viability**	5 and 10 hours after anther dehiscence	Chen *et al*., (2018)

Breeding system in *Piper nigrum* L. Splashing rain, according to Anandan (1924), aids in scattering pollen grains in many ways, either washing them down to lower spikes or carrying them to neighbouring vines. In black pepper, Gentry (1995) discovered apomixes. The presence of dry, powdery pollen in the cv Bangaka was noticed by Iljas (1960), who postulated geitonogamy. Based on their research in Puerto Rico, Martin and Gregory (1962) found that 32–64 percent of the pollen on the spike can be distributed into the air within 24 hours of exposure. Pollen lumps may disintegrate as a result of dew accumulation, according to them. Fresh pollen occurred in glutinous clusters dispersable in water in Sarawak, in the cv. Kuching (Warrd and Zevan, 1969). However, research conducted in Kerala, the world's black pepper variety hotspot, ruled out the significance of insects in pollination. Martin and Gregory (1962) and Semple (1974) both reported the presence of insects, implying that they play a part in pollination. Semple (1974) discovered that three species of Trigona bees are the most common visitors on Piper spp. in Costa Rica, and that they collect "huge amounts of pollen in their baskets" by working up and down the spikes and then travelling from spike to spike. Geitonogamy is a self-pollination technique in which pollen grains descend gravitationally. In plants with long pendent inflorescences, this is an effective method.

Pollination is frequently affected by heavy rains. Geitonogamy is favoured by pendent hanging spikes, spiral floral arrangement, sequential ripening of stigmas, and prolonged stigma receptivity. Martin and Gregory (1962) described two pepper pollination strategies that were both ineffective. In one method, pollen was scooped up and put to the stigma of selected spikes after mature anthers were opened with a scalpel. Spikes from male and female parents were brought together and rubbed with a camel hair brush in the other technique.

Alcohol, hot water, and excision were all used to emasculate men. In Sarawak, Warrd and Zevan (1969) developed a method of hand pollination that took use of the cv. Kuching's long protogyny stage. To avoid geitonogamy, all spikes on the receiving plant (female parent) were clipped prior to cross pollination. Branches were chosen at three or four locations, and they were wrapped in cheese cloth bags and left to produce spikes. Pollen from a male parent is transported to the stigma as soon as three or four spikes in the designated branch are receptive.

A part of the spike with newly opened anthers is cut off and placed on the end of a long pin, with the entire pollen cluster delicately brought into contact with the young stigma. According to reports, this procedure has a 50–75 percent success rate. Emasculation was used by Nambiar *et al.* (1978), who isolated the emasculated spikes in butter paper sacks. A fine pointed needle was used to scoop up the anthers from either side of the ovary during emasculation. The spike's unemasculated section is chopped away, and the spike is covered with a paper bag. Washing the spikes with distilled water and collecting the washings is how pollen grains are gathered. Pollination is done by sprinkling pollen suspension on the emasculated spike with a cotton swab. The setting has been reported to be around 6–12 per cent.

Ravindran *et al.* (1981) devised an efficient protogyny-based crossing technique. The lateral fruiting, plagiotropic branches of bush peppers of various cultivars were rooted. These dwarf flowering plants in pots were utilised to create a crossing block in the green house. Using nylon cloth, rainproof bolting cloth, or poly bags, these plants can be kept isolated either spatially or mechanically. Spikes are selected for crossing in such isolated plants, and pollination is carried out as soon as the stigmata become receptive.

A suitable number of anthers were obtained from a male parent in a tiny vial the day before and maintained in a desiccator over calcium chloride for dehiscence. A few drops of distilled water were added to the container the next morning, shaken well, and this pollen suspension was brushed onto the stigma or applied with an ink filler.

A high concentration of pollen grains in the solution is required for successful pollination, and this can be determined by examining a drop of suspension under a microscope. The pollination procedure was continued for a few days until anther emergence in the spike was seen. The unfertilized section of the spike was clipped off when pollination was ended. This procedure was quite successful, with a success rate of up to 82 percent, and emasculation was only required if there was only a very short delay between the male and female phases.

Floral biology of *Piper longum* L.

Piper longum is native of Indo-Malayan region and considered indigenous to the hotter parts of India (CSIR, 1969). *Piper longum* appears to be derived from two or three species that may include species from Malaysia and Indonesia. It was a product of either *P. longum or P. peepuloides* (Khushbu *et al*., 2011).

Piper longum was reported as a dioecious species (Rahiman, 1981 and Ravindran, 1990). Sujatha and Nybe (2007) identified bisexual type in *Piper longum.* The species *Piper longum* was reported to be apomictic (Ravindran, 2006).

Table 5: Floral characters of *Piper longum L.*

Sr. No.	Characters	Description	References
1.	**Spike type**	Cylindrical, compact, irregular and long	Mehra (1970) and Puri
		Female: Cylindrical, pedunculate	CSIR (1998)
		Female: Erect, Cylindrical	Ravindran (2006)
		Female: short, bold Male: long, slender	Jaleel (2006)
		Cylindrical and erect	Sujatha and Kanimozhi (2015)
		Cylindrical, pedunculate	Zaveri *et al.* (2010)
		Erect, Cylindrical, Glabrous	Nair (2012)
2.	**Spike colour**	Male: Immature spikes were dark green which turned to light yellow and further to dull yellow on maturity	Sujatha and Kanimozhi (2015)
		Female: Creamy white until fruit set, then colour changed to green	Chandran (2012)
		Female spike - colour of immature spike be yellow and mature green or black in Male spike - colour is green during immature stage and yellow during maturity.	Nair (2012)
		Immature spike - creamy yellowish white Mature spike - yellow white	Ravindran (2006)

		Female: black on maturity Male: yellow on maturity	Jaleel (2006)
3.	**Spike length:**	Female: 2.31 cm Male: 7.76 cm Bisexual: 6.35 cm	Sujatha and Kanimozhi (2015)
4.	**Spike fragrance**	Fragrant	Nair (2012)
5.	**Flower type**	Fused laterally and sessile	Ravindarn (2006) Nair (2012)
6.	**Bract type**	Peltate, orbicular	Ravindarn (2006)
		Sessile oblong and adnate to the Rachis	Nair (2012)
7.	**Style**	Absent	Ravindarn (2006)
8.	**Perianth**	Absent	Ravindarn (2006), Sujatha and Kanimozhi (2015)
9.	**Anther**	Bisexual: 3 Male: 2	Sujatha and Kanimozhi (2015)
10.	**Anthesis**	7.30 am to 4.30 pm	Sujatha and Kanimozhi (2015)
		7.30 am to 4.30 pm	Nair (2012)
		9.00 am to 11.00 am	Sujatha and Kanimozhi (2015)
		7.30 am to 4.30 pm	Nair (2012)
12.	**Time taken for complete opening of flowers in an inflorescence**	7 days	Sujatha and Kanimozhi (2015)
		7 days (all sex forms)	Kanimozhi (2010).
		7-8 days	Nair (2012)
13.	**Stigmatic lobes**	3-4	Ravindran (2006)
		Female: 4	Ravindran (2006)
		Bisexual: 2-6	Sujatha and
			Kanimozhi (2015)
14.	**Pollen fertility**	9.30 am (41.67%)	Sujatha and Kanimozhi (2015)

Floral biology of *Piper betle L.*

Piper betle is native to Central and Eastern Malaysia (Chattopadhyay and Maity, 1967).

Table 6: Floral biology of *Piper betle L.*

Sr. No.	Floral characters	Description	References
1.	**Spike type**	Axillary spike	CSIR (1969)
2.	**Spike colour**	Green in colour, turning to yellow later	Chaveerach *et al*., (2006)
		Female: Immature –Green **Male**: Mature – whitish sessile	Preethy *et al*., (2017)
3.	**Spike diameter**	**Male**: 0.50cm **Female:** 3mm	Chaveerach *et al*., (2006)
		Male: 0.40 cm **Female:** 0.50-0.60 cm	Preethy *et al*., (2017)
4.	**Spike length**	**Male**:3.0 to 12.0 cm **Female:** 2.5 to 4.0 cm	Chaveerach *et al*., (2006)
		Male: 5.97 cm **Female:** 2.40-2.80 cm	Preethy *et al*., (2017)
5.	**Flower**	Sessile	Preethy *et al*., (2017)
6.	**Peduncle length**	2-3cm	Chaveerach *et al*., (2006)
		3.07-3.077cm	Preethy *et al*., (2017)
7.	**Stigma (female)**	4 – 6 stigmas with pubescent texture	Chaveerach *et al*., (2006)
		6-9	Preethy *et al*., (2017)
8.	**Anthers**	2	Chaveerach *et al*., (2006)
9.	**Stamens**	2	Preethy *et al*., (2017)

Table 7: Important minor piper species.

Characters	*Piper Mullesua*	*Piper attenuatum*	*Piper galeatum*	*Piper wightii*	*Piper hymenopyllum*
Spike	Male spike:3-5 cm filiform, erect Female spike: 1 cm oblong, erect	Male spike 8-18 cm, Female spike 7- 15 cm	Filiform, pendulous Male spike-10-15 cm	Thin, filiform, Male spike -5-13 cm (gentle lemon fragrance), Female spike - 6-16 cm	Filiform, pendulous (4-8cm), 1-1.5cm long – peduncle, flowers- Spirally
Bracts	Peltate, stalked and orbicular	Sessile, adnate to rachis	Boat shaped structure	Sessile, adnate to rachis	Oblong, narrowed at the base and adnate with free margin
Stamens and anthers	2-3 Exerted beyond the bracts	Dithecous	2, anther 2 lobed	3 Dithecous	2-3(longitudinal slits)
Ovary	Ovate	Single	Obovate	Oval	Conical
Style	Absent	Absent	Absent	Absent	Absent
Stigma	3lobed pappilate sessile	3-4 lobed papillate	3-4 lobed	3 lobed pappilate	4 lobed, persistent stigma
Fruit	Small, Ellipsoidal, densely aggregated	Oblong (0.25-0.4 cm)	Green- ripening (bright yellow), oblong	Oval, free, spicy	Conical with persistent stigma

The betel vine land races grown in Malappuram District were Puthukodi, Chelan, Karinadan, and Nadan. Profuse flowering was noted in all land races during a characterisation investigation of Tirur betel vine varieties. Chelan was discovered as a male land race, while the other cultivars were all female. Chelan spikes were long, slender, and had a small peduncle. Female cultivars had medium-length spikes with medium-diameter spikes. The spikes were axillary and on the opposite side of the leaf. On the inflorescence axis, sessile naked florets were compactly grouped. In both male and female spikes, a bract covered each floret.

At the stage of anthesis, the two black stamens protruded from the mature male florets, which were yellow in hue. All other floret pieces were transformed into bracts and attached to the stem. Immature female spikes were green in color. Matured female spikes were identified by the presence of whitish, sessile stigmatic lobes. On ageing the stigmatic lobes became black. Number of stigmatic lobes in cultivars varied from six to nine. The stigmatic lobes became black coloured towards the end of spike maturation. Ranade *et al*. (2002) suggested RAPD method for a clear distinction between male and female betelvines or between types of landrace groups.

CONCLUSION

The pollination process exemplifies the value of biodiversity, demonstrating how each organism, insect, and animal contributes to the ecosystem. Pollination is responsible for a wide range of food, primarily horticulture crops, that we consume. Animal pollination benefits three-quarters of all crops in some way. It's uncertain how decreased biodiversity will disrupt ecosystem dynamics if animal extinctions continue at a pace of one per 16 years. Pollinators, which are critical participants in the reproductive biology of plants, the world's primary producers, are of particular importance. The flawless coupling of pollinator proboscis anatomy with plant flower shape, as well as the strategies plants utilise to lure reproductive aids to their food rewards, are the result of millions of years of evolutionary coadaptations. These mutually beneficial relationships are sometimes so specialized that the loss of one species threatens the existence of the other, raising troubling questions about the likely consequences of declining diversity in pollination networks. With respect to pollination biology, available research suggests that insects, wind, and selfing play a role for Neotropical Piper. Thus, The floral morphology and phenology is essential to understand the pollination biology of the plant.

FUTURE SCOPE

The similarity in floral morphology among species in this genus must have motivated that statement, along with an almost complete lack of information on the sexual reproduction characteristics of those species. Our study reinforces the need to associate floral morphology analysis with data on flower biology, and indicates future changes in studies involving reproductive traits associated with the phylogeny of the genus.

REFERENCES

Anandan, N. (1924). Observations on the habit per vine pepper with special reference to the reproductive phase. *Madras. Dep. Agric. Year Book*, 49–69p.

APG [Angiosperms Phylogeny Group] I. (1998). An ordinal classification for the families of flowering plants *Ann. Missouri Bot. Garden.*, *85*(4): 531-553. [online]. Available: http://www.bergianska.se/english/about-us/contact-us/staff/birgitta-bremer/other publications-before-2002/angiosperm-phylogeny-group-apg-1998-1.88364 [24 October 2018].

APG [Angiosperms Phylogeny Group] II. (2003). An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants. *Bot. J. Linn. Soc.* 141:399- 436. [on-line]. Available:https://academic.oup.com/botlinnean/article/161/2/105/2418337 [23 October 2018].

APG [Angiosperms Phylogeny Group] III. (2009). An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants. *Bot. J. Linn. Soc., 161:* 105-121: [on-line]. Available: https://academic.oup.com/botlinnean/article/
161/2/105/2418337 [23 October 2018].

APG [Angiosperms Phylogeny Group] IV. (2016). An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants. *Bot. J. Linn. Soc., 181*: 1–20. [on-line]. Available: https://academic.oup.com/botlinnean/article/181/1/1/2416499 [23 October 2018].

Bioversity International. (1995). *Descriptors for Black Pepper* (*Piper nigrum* L.). Bioversity International, Rome, Italy, 25p. [on-line]. Available: https://www.bioversityinternational.org/fileadmin/_migrated/uploads/tx_news/Descriptors_for_black_pepper______Piper_ nigrum_L. Descriptores_para_pimienta_negra_*Piper_nigrum*_L._338.pdf [28 October 2018].

Blume, K. L. (1830). *Zippelia*. *Systema Vegetabilium, 7*(2): 1614-1615.

Burger, W. C. (1971). Flora Costaricensis. In Burger, W.C (ed.), *Fieldiana Botany* Vol 35. Field Museum of Natural History, Chicago, pp. 5–218.

Chandran, A. (2012). Evolving superior types in thippali (*Piper longum* L.) utilising bisexual variants. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 76p.

Chattopadhyay, S. B. and Maity, S. (1967). *Diseases of Betelvine and Spices*. Indian Council of Agricultural Research, New Delhi. 1-32 pp.

Chaveerach, A., Mokkamul, P., Sudmoon, R., and Tanee, T. (2006). Ethnobotany of the genus *Piper* (Piperaceae) in Thailand. *J. Plant. People. Appl. Res., 4*: 223-231.

Chen, Y. S., Dayod, M., and Tawan, C. S**. (**2018). Anther dehiscence, pollen viability and stigma receptivity on cultivars of black pepper (*Piper nigrum* L.). Pertanika. *J. Trop. Agric. Sci*. *41*(2): 801-814.

CSIR [Council of Scientific and Industrial Research]. (1969). *The Wealth of India: Raw Materials,* Vol VIII. Publications and Information Directorate, New Delhi, 98p.

CSIR [Council of Scientific and Industrial Research]. (1998). *The Wealth of India: Raw Materials* Vol I- XI (Revised Edition). Publications and Information Directorate, New Delhi, 115p.

Dar, S. (2017). Pollination and evolution of plant and insect interaction. *J. Pharmacol Phytochem*, *6*(3): 304-311.

Decandolle, C. (1923). Piperacearum clavis analytica. *Candollea, 1*: 65–415.

Devi, W. D., Gajurel, P. R., and Rethy, P. (2016)**.** Phenology of *Piper mullesua* Buchanan Hamilton ex D. Don (Piperaceae) - a medicinally important dioecious plant. *E. Himalayan Soc. Spermatophyte Taxon., 10*(2): 239 - 247.

Figueiredo, R. A. and Sazima, M. (2000). Pollination biology of Piperaceae species in South Eastern Brazil. *Ann. Bot*., *85*: 455-460.

Fleming, T. H. (1985). Coexistence of five sympatric *Piper* (Piperaceae) species in a tropical dry forest. *Ecol*. *66*(3): 688-700.

Gentry, H. S. (1955). Apomixis in black pepper and jojoba. *J. Heredity, 46*: 8.

Hemanth, (2014). Molecular analysis of floral meristem identifying genes in black pepper (*Piper nigrum* L.). M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 78p.

Iljas, H. B. (1960). Some notes on the floral biology of black pepper (*Piper nigrum* L.). *Pemb.Besar Penji. Pert., 57*: 1–22.

Jaleel, J. (2006). Characterisation of long pepper (*Piper longum* L.) genotypes using morphological, anatomical and molecular markers. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 34p.

Jaramillo, M. A. and Manos, P. S. (2001). Phylogeny and patterns of floral diversity in the genus *Piper* (Piperaceae). *Am. J. Bot. 88*(4): 706-716.

Kalinganire, A., Harwood, C. E., Slee, M. U., and Simons, A. J. (2000). Floral structure, stigma receptivity and pollen viability in relation to protandry and self-incompatibility in silky oak (*Grevillea robusta* A. Cunn.). *Ann. Bot., 86*(1): 133-140.

Kanakamany, M. T. (1982). Formulation of key for identification of the different types of pepper (*Piper nigrum* L.). M.Sc. (Ag) thesis, Kerala Agricultural university, Thrissur, 78-92 pp.

Kanimozhi, K. (2010). Exploitation of bisexual variant in developing high yielding types of *Piper longum* L. M.Sc. (Hort.) thesis, Kerala Agricultural University, Thrissur, 43p.

Kanimozhi, K. and Sujatha, V. S. (2015). Reproductive biology of *Piper longum* L. *J. Trop. Agri., 53*(2): 206-212.

Kearns, C. A., Inouye, D. W., and Waser, N. M. (1998). Endangered mutualisms: the conservation of plant pollinator interactions. *Ann. Rev. Ecol. Syst., 29*: 83–112.

Khushbu, C., Roshni, S., Anar, P., Carol, M., and Mayuree, P. (2011). Phytochemical and therapeutic potential of *Piper longum* L. - a review. *Intl. J. Res. Ayur. Pharm*., *2*(1): 157- 161.

Kikuchi, D. W., Lasso, L., Dalling, J. W., and Nadav, N. (2007). Pollinators and pollen dispersal of *Piper dilatatum* (Piperaceae) on Barro Colorado Island, Panama. *J. Trop. Ecol., 23*(5): 603- 606.

Kunth, K. (1839). Bemerkungen die familie der piperaceen. *Linnaea, 13*: 562–726.

Linnaeus, C. (1753). *Species Plantarum*. Salvii, Stockholm, Laurentius Salvius Publishers, Sweden, 1-560 pp.

Martin, F. W. and Gregory, L. E. (1962). Mode of pollination and factors affecting fruit set in *Piper nigrum* L. in Puerto Rico. *Crop Sci., 2*: 295-299.

Muñoz, A., Becker, V.O. and Delabie, J. H. C. 2012. Ant (Formicidae) assemblages associated with Piper spp. (Piperaceae) in the undergrowth of an Atlantic rainforest remnant in southeastern Bahia, Brazil.

Sociobiol, 59: 741–754.
Mehra, P. and Puri, H. (1970). Pharmacognostic studies on Piplamul. *Indian J. Pharm*., *32*: 184- 186.
Nambiar, P. K. V., Pillai., V. S., Sasikumaran, S., and Chandy, K. C. (1978). Pepper research at Panniyur-a resume. *J. Plant. Crops*, *6*(1): 4-11.
Nepokroeff, M. (2011). The evolution of pollination systems in one of the largest plant families.*Ann. Bot., 24*: 145-157.
Nybe, E. V., Miniraj, N., and Peter, K. V. (2007). Black pepper. In: Peter, K.V. (ed). Spices- Horticultural Sciences, India, 56-60 pp.
Preethy, T. T., Elsy, C. R., and Pathrose, B. (2017). A preliminary study on spike characters of betel vine (*Piper betle* L.). *J. Med. Plant Stud*., *5*(3): 199-201.
Purseglove, J. W. (ed.). (1968). *Tropical Crops- Dicotyledon 2*. John Wiley and Sons, London, Burnt Mill, Harlow, Essex 56p.
Rahiman, B. A. (1981). Biosystematic studies in varieties and species of *Piper* occurring in Karnataka region. Ph.D. thesis, University of Mysore, Karnataka, 101p.
Ranade, S. A., Verma A., Gupta M., and Kumar N. (2002). RAPD profile analysis of betelvine cultivars. *Biol. Plant.* 45: 523-527.
Ravindran, P. N., Nair, M. K., and Mathew, P. A. (1981). Controlled crossing technique in black pepper (*Piper nigrum* L.). In: Vishveshwara, P. (ed.). *PLACROSYM IV/* ISPC [Indian Society of Plantation Crops]. CPCRI [Cental Plantation Crops and Research Institute], Kasaragod, 247–251 pp.
Ravindran, P. N. (1990). Studies on black pepper (*Piper nigrum* L.) and some of its wild relatives. Ph.D. thesis, University of Calicut, Kerala, 336p.
Ravindran, P. N. (ed.). (2006). Botany and Crop Improvement of Black Pepper. *Black Pepper* (13th Ed.). Hardwood Academy Publishers, India, 84-85 pp.
Rojas, D. L. (2017). Sex expression, breeding system and pollinators of *Piper caldense*
(Piperaceae) in the Brazilian Atlantic Forest**.** *Acta. Biol. Colomb, 22*(3): 370-378.
Ruiz, L. H. and Pavon, J. A. (1794). *Florae Peruvianae et Chilensis Prodromus*. Madrid Publishers, Spain, 12-55 pp.
Semple, K. S. (1974). Pollination in Piperaceae. *An. Missouri Bot. Garden., 61*: 868-871.
Silva, A. and Vieira, M. F. (2015). Phenology of two co-occurring *Piper* (Piperaceae) species in Brazil. *Aust. J. Bot*. *63*(7): 581-589.
Spices Board. (2018). Majorspice wise area and production 2016-2017 [on line]. Availablehttp://indianspices.com/sites/default/files/ma jorstatewise%20areaproduc tion1172018_1.pdf [23 October 2018].
Sujatha, V. S. and Kanimozhi, K. (2015). Reproductive biology of *Piper longum* L. *J. Trop. Agri. 53*(2): 206-212.
Sujatha,V. S. and Nybe, E. V. (2007). A new sex form in pippali (*Piper longum* L). *PGR Newsletter, 149*: 44-45.
Suwanphakdee, C., Masuthon, S., Chantaranothai, P., Chayamarit, K., and Chansuvanich, N. (2006). Notes on the genus *Piper* L. (Piperaceae) in Thailand. *Thai Forest Bulletin, 34*: 206-214.
Tebbs, M. C. (1989). The climbing species of New World Piper (Piperaceae). *Willdenowia. 19*: 175-189.
Trelease, W. (1927). Piperaceae hispaniolenses. *Feddes Repertorium*, *23*(18-25): 303–333.
Trelease, W. and Yuncker, T. G. (ed.). (1950). *The Piperaceae of Northern South America*. University of Illinois Press, Urbana, *2*: 442-838.
Tucker, S. C. (1982). Inflorescence and flower development in the Piperaceae. II Floral ontogeny of *Piper*. *Am. J. Bot. 69*(9): 1389-1401.
Warrd, P. W. P. and Zevan, A. C. (1969). Pepper. In: Ferwarda, F.P. and Wit, F. (eds.), *Outlines of Perennial Crop Breeding*, Wageningen, 409-426 pp.
Yuncker, T. G. (1978). The Piperaceae of Brazil II: Piper group V; *Ottonia, Pothomorphe, Sarcorhachis, Hoehnea*. *3*: 29–284.
Zaveri, M., Khandhar, A., Patel, S., and Patel, A. (2010). Chemistry and pharmacology of *Piper longum* L. *Int. J. Pharm. Sci. Rev. Res., 5*(1): 67-76.

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