Bloom sequences keep pollinators in fields

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Pollination is a concern for cardamom farmers as it is difficult to maintain pollinator populations in plantations between years. The innovative solution that is gaining popularity for ensuring quality pollination services to cardamom in South West India, is the use of managed forestry to create "sequential blooms" in mixed coffee and cardamom plantations.

Cardamom is a major crop in the Indian states of Kerala, Karnataka and Tamil Nadu. Indian cardamom is commonly grown in semi-cleared forest understory, in artificially shaded plantations or in the understory of planted tree plantations. Plantations range in size from less than one to over 100 hectares, although most cardamom plantations are small. Many small growers cultivate cardamom as a mixed crop with areca nut and coffee. In most parts of the Hills of Karnataka (part of the Western Ghats), where coffee is the major crop, coffee is grown on the slopes of the hills and cardamom is cultivated in the cooler valleys.

Canopy trees play an important role in maximizing cardamom production. They provide the shade needed by cardamom plants and the leaves that fall from them are used as mulch. In November and December, leaves fallen from shade trees are clustered around the base of plants to prevent the soil from drying during the summer dry season. Shade trees also provide nesting sites for pollinating bees and floral resources for pollinators at times of the year when cardamom is not blooming. Heavy use of chemical fertilizers and pesticides is in vogue, while herbicides are rarely used.

Cardamom plants flower continuously from the last week of April, or first week of May until the second week of October. Each cardamom flower lasts a single day. Flowers open in the early morning hours between 4 and 5 am and the anthers start to release pollen around 7:30 am. Though all the pollen grains are not released at once, they have all been released (and can be picked up by pollinators) by 10:30 am.

Insect pollinators are required for any valuable fruit production. A single flower receives as many as 130 visits from pollinators on a sunny day to just over 20 visits on a rainy day. If pollinated, each cardamom flower produces a single capsule containing about 10 seeds. The crop is self-compatible and does not require out-crossed pollen for fruit production; however, pollinator visits are critical for effectively and efficiently moving pollen from the anthers to the stigma. Thus, within the one day that a cardamom flower is open, it is essential that it is visited by insect pollinators depositing an optimal quantity (at least 18 pollen grains) per flower.

Major pollinators and their pollinator preferences

A recent study of cardamom's pollination ecology in the Western Ghats found a diversity of bees, flies, butterflies and bird species visiting cardamom flowers. Few visitors, however, were found to be true pollinators. Of the observed 18 flower visitor species, only three: the Eastern honeybee *Apis cerana, Trigona iridipennis* and *Ceratina hieroglyphica,*actually collected pollen on their bodies. All of these are bees, and all evidence indicates that bees are the dominant pollinators of cardamom in southwestern India, although the dominant bee visitors vary by plantation and region.

The most common bee pollinator of cardamom in southwestern India is *Apis cerana,* a honeybee species native to India. Other bees are also known to be effective pollinators of cardamom including *Apis dorsata, Trigona sp., Amegilla sp.* and *Ceratina hieroglyphica*. *Apis cerana* has been observed depositing from 3-23 grains of pollen per visit to a single cardamom flower and *Apis dorsata* has been observed depositing an average of 28 pollen grains per single visit.

Some of the smaller and less conspicuous bees may be even more effective. It was found that the small stingless bee *Trigona iridipennis* successfully pollinated between 83.3 and 95.5% of the flowers they visited (depending on the season). This is a significantly higher rate than that of the more common visitor, the Eastern honeybee, which only successfully pollinate 46.5% of the flowers they visit. The little bees also added to the services provided by *A. cerana*, that is, flowers that are visited first by *A. cerana* followed by *T. iridipennis* produced fruit 100% of the time, although the reverse visitation order did not result in higher pollination rates than single visits by *T. iridipennis*.

Several species of fast-flying long-tongued Amegilla bees also visit cardamom flowers. *Amegilla* with its long tongue (~15mm) is capable of exhausting all the nectar available in the corolla of cardamom flowers and may actually be the original pollinators of wild cardamom. *Amegilla* is very active in the beginning and during the end of the flowering season, when the flower density is low, and then is replaced by the native honeybees in midseason when flower density is high. Despite the potential importance of *Amegilla* evolutionarily and historically, currently *A. cerana* and *A.dorsata* bees are the most important pollinators in the production of cultivated cardamom.

Profile of best practices for cardamom pollination

Despite the diversity of pollinating bee species found visiting cardamom in southwestern India, pollination is a concern for cardamom farmers. As cardamom requires pollinators for fruit production, it is crucial to ensure that large numbers of pollinators are available during the blooming season. One of the major hurdles to ensuring cardamom pollination is maintaining pollinator populations in plantations between years. Most pollinators of cardamom are wild and thus move freely through the landscape. As cardamom does not bloom year round, pollinators may leave cardamom plantations once blooming finishes and they do not necessarily return the following season. *A. cerana* is the only major cardamom pollinator that is kept in managed hives, but many cardamom farmers cannot afford to rent them and many lack the knowledge to maintain them themselves. The other major cardamom pollinator in southwestern India is *Apis dorsata*. These bees are highly migratory and move their nests in response to resources. The presence of a single *A. dorsata* hive in a small plantation can provide for the majority of the necessary pollination services. *A. dorsata* has never been successfully domesticated and is the target of traditional honey collectors who in recent years have devastated *A. dorsata* populations in southwestern India. The expense associated with farmed *A. cerana* and the increasing rarity of *A. dorsata* has increased interest in maintaining a diversity of wild bees in cardamom plantations for pollination services.

An additional factor for developing interest in wild bees is the presence of a second crop that is similarly reliant on bees for pollination: coffee. Coffee has an even shorter blooming season, flowering for only a few days at a time in March/April. Although not as reliant on bees for fruit production as cardamom, it is known to need bees for maximized fruit production. Conveniently, many of the same pollinators visit both cardamom and coffee flowers, and coffee can tolerate the same levels of shade as cardamom requires. Often farmers have holdings of both on their land. The

Despite evidence showing the value of using multiple species of shade trees with appropriately timed flowering, the practice of planting a single shade tree species, specifically "silver oak", is still widespread.

Table 1. Cost and benefits of best practices

Practice	Costs	Benefits
Shade trees selected for flowering schedule (planting a floral calendar).	Does not allow regulation of shade during each growing season (except when timber trees are also grown) Potential decrease in yields due to over shading. Potential increase in pests and diseases.	Ensures supply of pollinators and associated increased yields. Provides extra income from selective logging. Provides extra income from growing a third crop – black pepper.
Replanting shade trees to use calendar species in preexisting plantations.	Expensive to remove trees, buy seedlings, plant seedlings. Reduced or no income from cardamom while calendar trees grow.	Increases long-term value of plantation and future fields.
Planting calendar trees in new plantation.	Similar cost to planting a monoculture of timber trees with no floral value.	Increased pollinator numbers in fields and associated increases in yields and income from cardamom and coffee production.
Tolerating/protecting *Apis cerana* bee nests.	No cost.	Additional income from honey collection. Free pollination services for cardamom and coffee.
Keeping A. cerana domestic hives.	Must purchase hive boxes and other bee keeping equipment. Costs associated with learning how to maintain bees.	Without a floral calendar, likely be necessary to maximize cardamom yields.
Tolerating/protecting Apis dorsata bee nests.	If maintained, little income from honey (honey collection destroys hives).	Free pollination services for cardamom and coffee.
Tolerating/protecting other pollinating bees (Amegilla sp, Trigona sp, etc.)	No cost.	Free pollination services for cardamom and coffee.
Limited pesticide use. Timing of pesticide applications and using bee safe pesticides.	Increased risk of pest outbreaks.	Reduced input costs. Reduced risk of declining yields due to low pollinator numbers, and low numbers of beneficial insects.
Maintaining multiple crops.	Requires knowledge of multiple crops and more skilled labor for harvest.	Diversified income from land. Ensuring income each year. Maximizing yields on small land holdings.

innovative solution that is gaining popularity for ensuring quality pollination services to cardamom and coffee in southwest India, is the use of managed forestry to create "sequential blooms" in mixed coffee and cardamom plantations. Farmers of cardamom and coffee plantations often plant economically valuable timber trees or betel nut trees (a crop of domestic value) to provide shade while maximizing the economic value of their plantations. As concern about declining pollination services has increased, however, a new approach to shade trees is emerging.

Instead of monocultures of timber trees, many farmers are now planting a diversity of flowering tree species that in combination provide floral resources in plantations year round. This flower scheduling provides reliable pollen and nectar resources for native bees at times of the year when neither cardamom nor coffee is blooming. One well-documented example is the use of two species of *Schefflera (S. venulosa* and *S.wallachiana).* Both of these tree species have flowers attractive to bees. Both flower almost immediately after coffee finishes blooming in the region and just before cardamom begins, thus greatly reducing the number of bees that leave plantations during the off season. By providing year round floral resources, farmers are ensuring that there will be enough bees around to pollinate cardamom and coffee flowers during the appropriate seasons. Additional benefits in the use of diverse bloom sequences is that the trees provide nesting sites for many bee species; can be used to support a third crop in mixed cropped plantations -most commonly black pepper and some of the trees can also be selectively logged for timber production.

Knowledge base of best practices

At the Zonal Agricultural Research Station in Mudigere, India, cardamom and coffee planters are trained to understand the importance of pollinators and how to maintain bee colonies. Between 2000 and 2005, twenty training programmes were run by the Station, each serving approximately 30 farmers. Some of these programmes were conducted in villages rather than at the research station to ensure that the information provided in the programmes reached poor farmers. The training included information on how to locate bee colonies, "hiving" and maintaining colonies. In every programme the importance of honey bees *(A. cerana and A. dorsata)* as pollinators of cardamom and coffee was given more emphasis than the use of these species for honey production. These training programmes were supported by the Indian Council of Agricultural Research, New Delhi, and the Ministry of Rural Development of the State. During the five years, approximately, 600 farmers were trained and a recent survey has shown that at least 20% of them are now keeping bee colonies on their plantations. The Cardamom Board of India also has started to conduct similar training programmes. More training is needed to encourage the use of bloom sequences, but the level of governmental sponsored programmes to educate cardamom farmers throughout southwest India is already extensive and continues to grow.

Costs and benefits of best practices

More and more evidence is pointing at the overwhelming benefits of using floral calendars in cardamom plantations in India. The table on page 10 indicates costs and benefits of using floral calendars as well as related practices associated with this and other cardamom pollination-oriented practices. This list is generated based on cardamom production in India, but very similar considerations are likely to exist in other cardamom growing regions of the world.

Challenges and opportunities for wider adoption

One of the major challenges to increasing the use of floral calendars in cardamom and coffee producing regions of the southwest India is the prevalence of other strategies for providing shade in plantations. Although there are no studies documenting the differences between these practices, the "silver oak" approach is widely considered by agricultural scientists in the area to have strong negative effects on bee populations in coffee and cardamom plantations. In fact, in the last decade, there has been a notable decline in coffee and cardamom yields throughout the Western Ghats, which is generally attributed to the low bee numbers found in monocultural plantations. To increase the number of cardamom farmers utilizing bloom sequences, it is essential to increase research showing the value associated with them and the problems with using a monoculture of shade trees. A priority for increasing the prevalence of managed bloom sequences is to improve our knowledge of the flowering phenology of shade trees in existing plantations throughout the Western Ghats. While some trees such as the *Schefflera sp.* are well studied and are known to have phenologies conducive to use in floral calendars in southwestern India, trees are long-lived and phenologies change regionally. Much more extensive lists of tree species are needed for each sub region of Kerala, Karnataka and Tamil Nadu. These will be locally useful for providing floral resources between the cardamom and coffee flowering seasons, but will not compete for bees during these crop's blooming season. An additional hurdle is the time it takes for trees to reach reproductive maturity. Thus, it may be better to encourage farmers to implement this practice in their new fields, rather than in those already in operation. There is real promise in encouraging the use of bloom sequences in new plantations, but without convincing farmers to convert their current plantations, progress will continue to be slow.

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