Evolution of hybridization techniques in coconut

First hybrid to modified ground pollination

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Artificial pollination in dwarf palm

Coconut (Cocos nucifera L.) is one of the most important perennial crops of the tropics, providing food, livelihood and a diverse range of products to millions of people worldwide. In India, tall coconut varieties constitute the major share of the cultivated area. Coconut hybrids, developed by combining the desirable attributes of dwarf and tall varieties, offer several advantages, including early flowering, higher nut production, and improved copra and oil yields. Despite these advantages, however, the area under hybrid coconut in India remains relatively small. This is largely attributed to the difficulties associated with large-scale production and timely supply of genetically authentic and high-quality hybrid planting material. The development of efficient, reliable and scalable hybrid seed production techniques remains an important area of technological advancement in coconut breeding.

Historical evolution of coconut hybridization in India

The history of coconut hybridization in India can be traced to the early recognition of hybrid vigour (heterosis) in coconut. The first coconut hybrid in the country was produced in 1932 by Dr. J.S. Patel using West Coast Tall as female parent and Chowghat Green Dwarf as male parent and the resultant hybrid progeny exhibited seedling vigour in the nursery, which is the world's first documented report of hybrid vigour in coconut (Patel, 1937). The first hybrid progenies were planted at Nileshwar (near Kasaragod) in 1934 for evaluation and these hybrids manifested earliness in flowering, increased nut and copra yield compared to the parents.

Although this early observation established the potential of hybridization for exploiting

superior performance, systematic large-scale production and adoption of coconut hybrids developed only several decades later. During the period before the 1950s–1960s, only a very limited number of artificially produced hybrids appear to have been developed and distributed. However, sufficient evidence indicates that natural cross-dwarf (NCD) hybrids were already in circulation, having been identified primarily by their characteristic morphological differences at the seedling stage in nursery populations.

What is a Natural Cross Dwarf (NCD) Hybrid?

Tall varieties of coconut are predominantly cross pollinated, whereas dwarf varieties generally exhibit a high degree of self-pollination. However, when dwarf palms are grown in proximity to tall varieties, natural inter-varietal cross-pollination can occur. The resulting seedlings often exhibit distinct morphological differences from typical seedlings of the dwarf female parent. In particular, seedlings showing deviations in petiole colour accompanied by greater vigour could be readily identified in the nursery and selected as Natural Cross Dwarf (NCD) hybrids.

NCDs thus represented one of the earliest and simplest approaches to exploiting natural cross-pollination and hybrid vigour in coconut. NCD production did not involve deliberate pollination between identified male and female parents. Instead, the dwarf palm served as the known female parent, while the pollen source was an unknown tall or other compatible palm in the surrounding plantation. NCD seedlings were reported to possess several desirable characteristics compared with typical dwarf progenies. They were early bearers, produced more leaves, with a higher rate of leaf and spadix production. Importantly, the nuts and copra were considered to be of good quality, resembling those of tall varieties and being superior in quality to those of the dwarf parent. Natural-cross dwarf hybrid palms were also reported to be heavy yielding and to produce copra with a high oil content (Satyabalan, 1956).



Modified ground pollination

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An important advantage of NCD production was its simplicity and low technical requirement. No specialized pollination technique was necessary, and promising seedlings could be identified visually in the nursery based on their distinctive petiole colour and vigorous growth. This made NCD seedlings particularly attractive for rapid multiplication and distribution when organized hybridization techniques were still in their early stages.Despite these advantages, NCDs had an inherent limitation: the pollen parent was neither identified nor controlled. Consequently, the genetic composition of individual NCD seedlings could vary considerably, as could the magnitude and nature of heterosis expressed by them. Selection based primarily on petiole colour and nursery vigour could not guarantee the presence of a specific combination of desirable parental traits. Furthermore, pollen could originate from neighbouring palms of unknown genetic background, making it difficult to establish the identity, uniformity and reproducibility of the resulting progenies.

However, controlled pollination allowed breeders to select specific female and male parents with complementary characteristics and deliberately combine their desirable traits. It also enabled the identity of both parents to be maintained, facilitated the production of more uniform progenies, and provided a reliable basis for systematic evaluation of hybrid performance. Thus, while NCDs represented an important early exploitation of naturally occurring hybrid vigour, the limitations of uncontrolled pollen sources ultimately provided a strong impetus for the development of systematic and scientifically controlled coconut hybridization programmes.

An interesting field-level approach to coconut hybrid production has been practiced in certain coconut-growing areas

Feature	Natural pollination / Natural crossing	Emasculated, non-bagged pollination	Artificial / Controlled pollination	Modified ground pollination
Basic principle	Female flowers receive naturally available pollen; no deliberate pollen application	Male flowers are removed from selected female inflorescence, but it is not isolated; pollen comes from surrounding palms	Female inflorescence is emasculated, bagged and deliberately pollinated with pollen from a known male parent	Controlled pollination is retained, but pollen is delivered to the bagged inflorescence from the ground through a tube/device
Pollen parent	Unknown	Not guaranteed / usually unknown	Known and selected	Known and selected
Parentage certainty	Very low	Low (surety only about female parental palm)	High	High, provided emasculation, bagging and pollen handling are proper
Labour requirement	Very low	Low to moderate	High	Moderate; reduces repeated climbing
Cost	Very low	Low	High	Lower than conventional artificial pollination
Need for skilled climbers	Minimal	Required mainly for emasculation	High; climbing required for emasculation and repeated climbing for pollination	Much lower; climbing mainly for emasculation, bagging and bag removal
Risk of unwanted pollen contamination	Very high	High, because inflorescence remains exposed	Very low when properly bagged and handled	Very low when properly bagged
Hybrid purity	Not assured	Not assured	High	High
Setting percentage	Highly variable	Variable; depends on surrounding pollen source	Generally, about 25-30%,	approximately 25-28 %
Major advantage	Simple, inexpensive and requires little intervention	Practical way to increase chances of cross-pollination avoiding other complications involved in artificial pollination	Precise combination of desirable parents and production of identified hybrid combinations	Combines parental control with reduced climbing, labour and cost
Major limitation	Male parent cannot be identified; progeny is variable	Male parental source cannot be guaranteed	Expensive, labour-intensive and dependent on skilled climbers	Requires suitable equipment, proper bagging and pollen handling
Best suited for	General seed production and natural populations	Farmer-level production where suitable pollen sources are nearby	Research, breeding programmes and commercial hybrid seed production and relatively disease-free planting material production	Large-scale/farmer-participatory hybrid seed production where climbing is a constraint

of the Cumbam–Theni region of Tamil Nadu, particularly in some private plantations. In this approach, inflorescences of selected dwarf mother palms, especially Malayan Yellow Dwarf (MYD), are emasculated to prevent self-pollination. However, unlike fully controlled hybridization, the emasculated inflorescences are not subsequently bagged. Since West Coast Tall (WCT) palms are planted along the boundaries of the plantations, pollen from neighbouring tall palms can reach the receptive female flowers and effect natural cross-pollination. The nuts produced from these inflorescences are subsequently raised as seedlings, and progenies exhibiting desirable nursery characteristics, particularly vigorous growth and other phenotypic attributes indicative of hybrid vigour, are selected as putative hybrids. This practice can be regarded as an intermediate stage between natural cross-pollination and fully controlled hybridization, combining deliberate emasculation of the female parent with reliance on natural pollen dispersal from neighbouring palms. It provided a relatively simple and practical means of obtaining potentially hybrid progenies under field conditions without the intensive labour and technical requirements associated with complete controlled pollination.

However, the method has an important limitation: the pollen parent cannot be established with certainty. Since the emasculated inflorescences remain exposed, pollen from WCT palms as well as from other neighbouring palms of unknown genetic background may contribute to fertilization. Consequently, the resulting seedlings cannot be considered genetically confirmed hybrids solely on the basis of their field origin or superior nursery vigour. They are more appropriately regarded as putative hybrids or open-pollinated progenies, unless their parentage is subsequently verified using suitable genetic or molecular methods. Nevertheless, this field-level practice is historically significant because it illustrates the gradual evolution of coconut hybridization technology-from uncontrolled natural crossing, through partial manipulation of pollination, to fully controlled crossing with known male and female parents. It also demonstrates how practical experience in farmers' and private plantations contributed to the progressive development of more systematic approaches to coconut hybrid seed production.

T × D and D × T hybrids

Two major categories of coconut hybrids emerged based on the direction of the cross: Dwarf × Tall (D × T) and Tall × Dwarf (T × D). In a D × T cross, the dwarf palm is used as the female parent and the tall palm as the male parent, whereas in a T × D cross the tall palm serves as the female parent and the dwarf palm as the pollen parent. Examples include Chandra Sankara and Kalpa Sankara among D × T hybrids and Kera Sankara and Chandra Laksha among T × D hybrids.

Beginning of systematic artificial hybridization

A major transition in coconut hybrid seed production occurred during the 1960s and 1970s, when organized hybridization programmes began to replace reliance on naturally occurring crosses. The Department of Agriculture, Government of



Kerala, initiated a systematic hybridization programme for the production of Tall × Dwarf (T × D) hybrid coconut seedlings through the erstwhile Coconut Farm, Nileswar. This programme represented an important step towards the planned production of genetically defined coconut hybrids on a larger scale.

For implementing the programme, West Coast Tall (WCT) palms with desirable characteristics for use as female parents were identified in selected farmers' fields located in four important coconut-growing areas of Kannur district, namely Varam, Koodakkadavu, Muzhuppilangad and Dharmadam. These locations were selected based on the productivity and performance of the palms. The field-level implementation and technical supervision of the hybridization programme were carried out through a coordinated team comprising agricultural personnel and trained palm climbers.

An Agricultural Officer from the Coconut Farm, Nileshwar was assigned responsibility for overall monitoring of the hybridization programme. At each hybridization centre, an Agricultural Demonstrator deputed from the Coconut Farm served as the official responsible for coordinating and managing the field activities, with the assistance of a group of skilled pollinators. Selected palm climbers were trained in the techniques of controlled pollination at the beginning of every hybridization

season. Each pollinator was provided with a pollination register to systematically record details of the palms pollinated, including the relevant pollination operations and dates. During the hybridization season, pollination operations commenced early in the morning, generally around 7:00 a.m. Pollen collected from Dwarf palms of the Chowghat Orange Dwarf (COD) variety maintained at the Coconut Farm, Nileshwar and at CPCRI, Kasaragod, which was regularly supplied to the trained pollinators. The controlled pollination of selected WCT female palms with COD pollen enabled the systematic production of T × D hybrid seed nuts. The resulting hybrid seedlings were initially distributed through agricultural extension offices and, subsequently, through block-level agricultural offices, facilitating their dissemination among farmers.

Following the establishment of Kerala Agricultural University (KAU) in 1971-72 and the transfer of the Coconut Farm, Nileshwar to KAU, the hybridization programme in Kannur continued under the monitoring and supervision of the University. Thus, the organized programme initiated by the Department of Agriculture marked an important phase in the evolution of coconut hybridization in Kerala, laying the foundation for more systematic approaches to controlled pollination and large-scale production of hybrid planting material.

During the late 1980s and 1990s, the technology was further extended to more farmers' fields, particularly in Chavakkad, Guruvayoor, Nattika and nearby areas of Trichur District. The scheme for production of D x T hybrid coconut seedlings was confined to Chavakkad region in Thrissur district (extended to Perumbadappu in Malappuram) utilizing the dwarf palms of Chowghat Orange Dwarf variety available in farmers' plots.

During the period from 1970 to 1995, most coconut hybrids released in India were T × D (Tall × Dwarf)combinations. Subsequently, increasing emphasis was placed on D × T (Dwarf × Tall) hybrids because of the practical advantages of using dwarf palms as female parents in large-scale hybrid seed production. Artificial pollination of tall female palms is labour-intensive, as repeated climbing is required to access the inflorescences for emasculation, bagging, pollen application and subsequent removal of the pollination bags. In contrast, the shorter stature of dwarf palms makes these operations considerably easier, safer and efficient.

The systematic development of D × T hybrid seed production gained further momentum following the establishment of the Seed Garden Complex at Munderi, Nilambur, over an area of approximately 505 ha, in 1979. To strengthen the dwarf seed-parent base, about 10,000 seed nuts of Malayan Dwarf varieties were imported from Malaysia and planted at Munderi Farm from 1985 onwards. These plantings subsequently provided an important source of dwarf female parents for hybrid seed production. Large-scale D × T hybrid seed production at Munderi Farm commenced in the early 2000s, marking an important phase in the expansion of D × T hybridization in India.

The transition from T × D to D × T hybridization was therefore driven not only by breeding considerations but also by the practical requirements of efficient and economical large-scale hybrid seed production. Nevertheless, large-scale D × T production presented its own challenges, particularly the limited availability of suitable dwarf mother palms and the alternate-bearing behaviour of dwarf palms, which could affect the regularity and scale of seed production. These constraints subsequently stimulated efforts to improve pollination efficiency and develop more economical hybridization methods, including modified ground pollination techniques.

Release of coconut hybrids and the role of CPCRI

The systematic hybridization programmes undertaken in India resulted in the development and release of several commercially important coconut hybrids. Among the early hybrids developed by ICAR-CPCRI, Chandra Sankara and Chandra Laksha were officially released for cultivation in India in 1985. Kerala Agricultural University also released Kera Ganga, Ananda Ganga and Laksha Ganga hybrids during the same period. As mentioned earlier most the hybrids released during this period were T X Ds types with the exception of Chandra Sankara (COD X WCT) which belonged to D X T category. These hybrids demonstrated the potential of coconut hybridization to combine early bearing and enhanced productivity with desirable copra and oil characteristics. Nevertheless, despite several decades of efforts, adoption remained limited, primarily due to the inadequate availability of quality planting material.

An important milestone in the subsequent evolution of hybridization was the development of hybrids specifically suited to

root (wilt) disease-prevalent tracts. Since conventional plant protection measures are inadequate for managing the root (wilt) disease, development and deployment of resistant or tolerant planting material became an important component of disease management.

In this context, ICAR-CPCRI Regional Station, Kayamkulam developed and released Kalpa Sankara, a root (wilt)-tolerant coconut hybrid, through the cross between root (wilt)-disease-free Chowghat Green Dwarf (CGD) as the female parent and root (wilt)-disease-free West Coast Tall (WCT) as the male parent. The hybrid recorded a ten-year cumulative average yield of 84 nuts per palm per year, a copra outturn of 2.50 t ha^{-1} and an oil yield of 1.70 t ha^{-1}. Its increasing demand in root (wilt)-affected areas created a need for technologies capable of producing the hybrid on a much larger scale.

Evolution of artificial pollination techniques

The development of coconut hybridization was closely associated with progressive improvements in artificial pollination technology. Successful controlled hybridization requires a clear understanding of coconut floral biology. The coconut inflorescence, or spadix, consists of a central rachis bearing numerous rachillae, with male flowers distributed along the rachillae and female flowers generally occurring towards their basal portions. Male flowers normally open before female flowers in tall palms, providing a natural mechanism that favours cross-pollination. In dwarf varieties, however, the male and female phases overlap considerably, resulting in greater possibilities of self-pollination.

The conventional artificial hybridization procedure therefore involved selection of superior parental palms, collection and processing of pollen from the male parent, emasculation of the female inflorescence, bagging to prevent unwanted pollination, and application of pollen during the receptive stage of the female flowers.

The earliest large-scale hybridization programmes used relatively simple methods for pollen application. During the 1970s, receptive female flowers were pollinated using a camel brush or the midrib of a coconut leaf, dipped into small glass vials containing coconut pollen. With increasing experience and the expansion of hybrid seed production, the pollen applicator became more widely adopted. The pollen was mixed with purified talc and applied as a cloud over the receptive female flowers.

Refinement of pollen collection and preservation

As controlled hybridization became more systematic, attention was also given to improving pollen collection and preservation. Male flowers were collected from selected male parental palms before individual flowers opened. The collected flowers were processed to separate the pollen, dried under controlled conditions and sieved to obtain pollen of suitable quality. Pollen was subsequently stored in a desiccator containing fused calcium chloride, allowing it to retain viability for approximately 10-12 days without appreciable loss. These refinements made it possible to synchronize pollen availability with the receptive phase of the female flowers and thereby improve the efficiency of controlled hybridization.

From climber-dependent pollination to ground-level pollination

Despite improvements in artificial pollination, conventional hybrid seed production continued to depend heavily on skilled coconut climbers. This became a major constraint, particularly when hybrid production was expanded to farmers' fields. The problem was especially acute for T × D hybridization, where repeated climbing of tall female palms was necessary for different stages of the pollination process.

The requirement for repeated climbing also increased production costs and posed occupational risks. In the case of dwarf female palms, frequent climbing could additionally increase the possibility of damage to fronds and petioles. These limitations stimulated efforts to develop technologies that would enable pollen application from ground level.

Pole pollination

For effective and speedy assisted pollination, a simple device has been developed. It consists of a polythene squeeze bottle, a rubber tube and bamboo pole. The squeeze bottle is tied at the end of a bamboo pole or aluminium rod of 2-3 m length. A rubber tube with a rubber bulb at one end is connected to the bottle just below the neck. When the rubber tube is pressed, it injects air into the squeeze bottle and in turn, the pollen-talc mixture present inside the bottle is released as a cloud. When the receptive female flowers are to be pollinated, the nozzle of the bottle is placed near the inflorescence and the rubber tube is pressed. The pollen-talc mixture released will cover the inflorescence effecting

the pollination. The process is repeated on the 1st, 3rd and 5th day etc. (alternate days) starting from the day when the first female flower comes to receptivity. When the stigmas tum brown and black the female flower is no longer receptive for pollination. By this method most of the dwarf palms can be pollinated from the ground level. The limitation of this method is that it is applicable only to dwarf palms and involves practical difficulties, particularly in steadily holding and accurately directing the tube towards the small opening in the transparent plastic window of the pollination bag. Consequently, the method is no longer in practice. Skilled climber depended pollination continued in all research stations and seed gardens under Department of Agriculture/ Horticulture until 2018-19.

Devakumar and co-workers developed a ground pollination technique in 2018 for artificial pollination of tall palms from ground level. This technology was subsequently refined at ICAR-CPCRI to suit the production of D × T hybrids, particularly the CGD × WCT (Kalpa Sankara) hybrid. The modified ground pollination technique developed in 2019 represented an important step in the evolution of coconut hybridization by reducing dependence on skilled climbers for repeated pollen application.

Modified ground pollination: a major technological refinement

The modified ground pollination technique involved several improvements to the earlier ground pollination system. A flexible 6-mm PVC pipe was used for pollen delivery, replacing the larger-diameter clear PVC tube. The earlier vertical air blower powered by a 12-volt battery was replaced with a 5-litre hand-operated pressure sprayer. A 6-mm micro-sprinkler attached to an adapter was fitted to the upper end of the delivery pipe to facilitate more uniform distribution of the pollen-talc mixture within the pollination bag.

Under the modified system, the pollination bag is connected to the pollen delivery tube and installed on the emasculated inflorescence. At the onset of the female phase, pollen mixed with purified talc is introduced into the system and delivered to the receptive flowers using manual pressure. Pollination is repeated until all female flowers on the inflorescence have completed their receptive phase.

Studies conducted at different ICAR-CPCRI centres and AICRP Centres during 2019–2025 recorded fruit-setting rates of 18.5-25.0% using the modified ground pollination technique, which were comparable with those obtained under manually assisted pollination. This was tested across five stations covering four states and evaluated over a six-year period demonstrating its potential for efficient hybrid seed production.

The technique also offers substantial economic advantages. A ground pollination unit costs approximately ₹400, while a 5-litre sprayer costing about ₹600 can be used to pollinate around 25 palms. Thus, the effective sprayer cost per palm is only₹24 (₹600/25). The charge for a skilled climber to install one pollination unit is approximately ₹70. For six inflorescences, the cost of emasculation and bagging is about ₹420, while bag removal costs another ₹420. Accordingly, the total cost of pollinating six inflorescences using the ground pollination system is approximately ₹1,264 (₹424 + ₹420 + ₹420). This compares favourably with the conventional cost of approximately ₹2,400 per palm for pollinating six inflorescences. Thus, the modified ground pollination technique can achieve nearly 50% reduction in the cost of hybrid seed nut production.

Reducing dependence on skilled climbers

Besides reducing production costs, the technique offers several important operational advantages. Hybridization activities can be controlled and monitored from ground level, reducing dependence on skilled coconut climbers and minimizing repeated climbing. With the modified technique, only two climbing operations per inflorescence are required, compared with approximately eight climbing operations under the conventional method. The involvement of skilled climbers is therefore largely restricted to emasculation-cum-bagging and subsequent bag removal. The technique also substantially reduces the time required for pollen application: approximately 1.5 minutes are sufficient for pollen application from the ground, compared with 10–12 minutes required for climbing the palm and applying pollen manually. These advantages make modified ground pollination a cost-effective, labour-saving and operationally efficient technology for large-scale coconut hybrid seed production.

Future prospects

The evolution of hybridization techniques in coconut is continuing. Further refinement of the ground pollination system is proposed through the development of a

lightweight and rapid pressure-delivery mechanism and the integration of its components into a sensor-based, user-friendly Ground Pollination Kit. Wider availability of such kits could facilitate decentralized hybrid seed production and reduce dependence on specialized labour. Further opportunities also exist for improving pollen management. The establishment and utilization of pollen cryo-preservation facilities could help overcome temporal and spatial constraints in pollen availability. Similarly, improvements in pollen formulation and the use of suitable biomolecules may provide opportunities for enhancing fruit set following artificial pollination.

Another important component of hybrid seed production is reliable identification of hybrid seedlings at the nursery stage. Hybrid seedlings can be distinguished using characteristics such as early germination, petiole colour, collar girth, leaf number and leaf and leaflet dimensions. However, petiole colour still remains one of the most widely used visual markers for identifying hybrid seedlings during nursery selection. Identification of molecular markers associated with hybrid vigour in coconut will be a game changer in selecting superior hybrids at the nursery stage.

Since the availability of suitable mother palms are very limited, high yielding palms maintained in farmers' fields can be effectively utilized as an important resource for the production of quality planting material and hybridization programme. The work done by ICAR-CPCRI with the support of Kerala State Department of Agriculture during 2019-2021 in identifying mother palms, establishing decentralised community nurseries and produce quality planting materials including hybrids in a farmer participatory mode was a successful initiative. The work done by the Changaroth Federation of Coconut Producer Societies (Kozhikode District) and Bharanikavu Panchayat Coconut Producer's Federation (Alappuzha District) in producing hybrids in a farmer participatory approach were commendable. Such farmer led initiative for hybrid seedling production can be replicated and upscaled in coconut-growing regions/states with appropriate technical support, thereby strengthening local production and ensuring timely availability of quality hybrid planting material to farmers.

Conclusion

The history of coconut hybridization in India reflects a gradual transition from observation to selection, from selection to controlled crossing, and from manual pollination to mechanized ground-level pollination. The early recognition of hybrid vigour in 1932 provided the scientific foundation for subsequent exploitation of heterosis. The large-scale hybridization programmes initiated during the 1970s established systematic T × D hybrid production, while subsequent emphasis on D × T hybrids offered practical advantages in hybrid seed production. The development of disease-tolerant hybrids such as 'Kalpa Sankara' further demonstrated the value of hybridization in addressing region-specific production constraints.

The subsequent development of ground pollination and its refinement into the modified ground pollination technique represents an important technological milestone. By reducing the need for repeated climbing, lowering pollination costs and enabling hybrid seed production under conditions of limited availability of skilled climbers, the technology has considerable potential for scaling up coconut hybrid production.

The future of coconut hybridization will depend not only on the development of superior parental combinations but also on efficient systems for large-scale production, quality assurance, nursery identification and distribution of hybrid planting material. Strengthening farmer groups and FPOs through scientific training, systematic identification of suitable mother palms, assisted pollination and community nurseries will enable decentralized and sustainable production of quality hybrid coconut seed and planting material, thereby improving the availability of superior planting material to farmers. Wider adoption of improved pollination technologies, together with continued breeding for productivity, quality and adaptation to biotic and abiotic stresses, can substantially contribute to increasing coconut productivity and farm income in India.

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