Centenary Publication - 2

Root (wilt) Disease of Coconut

Bench to Bunch Strategies

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May 2015

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CONTENTS

ETIOLOGY

Introduction

Coconut (*Cocos nucifera* Linn., Family -Arecacea) is the most widely cultivated tropical palm in India. As a traditional plantation crop, the palm is intimately related to the economic, social and cultural life of a vast multitude of marginal and small coconut growers. Root (wilt) disease (RWD) is one of the major biotic stresses that limit the productivity of coconut in India particularly Kerala. The disease was first noticed in 1882 in Erattupetta area of Meenachil taluk in Kottayam district of Kerala. Around 1907 the disease was reported from Kaviyoor and Kalloopara areas of Tiruvalla taluk in Pathanamthitta district and later from Kayangulam area of Karthikapally taluk in Alappuzha district. Now, the disease is prevalent in a contiguous manner in all the eight southern districts of Kerala starting from Thiruvananthapuram to Thrissur and in isolated patches in the remaining six northern districts of the state. Apart from this, the disease is reported to be present in isolated spots in Theni, Coimbatore, Tirunelveli and Kanyakumari districts of Tamil Nadu, Dakshin Kannada district of Karnataka and in Goa. The annual loss due to the disease was estimated to be about 968 million nuts and the monetary loss assessed in terms of loss in husk, copra yield and leaf on the basis of 1984 price index of coconut was in the magnitude of about Rs.3000 million.

Abnormal inward bending of the leaflets termed ribbing or flaccidity, yellowing and marginal necrosis of leaflets are the diagnostic symptoms of the disease (Fig.1). Palms of all age groups are affected. However, palms contracting the disease in the pre-bearing age may not come to flowering and bearing. Rotting of roots, shedding of immature nuts, drying up of spathes and necrosis of spikelets in unopened inflorescences are also associated with the disease. The husk, kernel and oil of the nuts of the disease affected palms are of poor quality. The disease also causes physiological and biochemical changes in the palm. This slow spreading disease is non-lethal but debilitating.

Fig. 1 Symptoms of root (wilt) disease of cocunut

Phytoplasma- the causal organism of coconut root (wilt) disease

Known since 1880's, the disease has long been a concern to the coconut researchers because of its spreading nature and the importance of the coconut in the subsistence agriculture of farmers in south India. Investigation on the etiology of root (wilt) disease was initiated by Butler in 1908. He observed the association of the fungus *Botryodiplodia theobromae* with the roots of the affected palms and suggested that rotting due to this fungus could be the cause of the disease. Though subsequent investigations showed constant association of *Rhizoctonia solani*, *R. bataticola*, *Cylindrocarpon effusum*, *Fusarium equiseti* in the roots of disease affected palms, all these pathogens failed to produce the characteristic symptoms of the disease under artificial inoculation studies. Failure in establishing the fungal etiology instigated the research on the pathogenecity of bacteria, viruses, viroids and nematodes. Systematic and coordinated research work conducted over seven decades to identify the causal organism of this disease has ruled out the role of fungi, bacteria, nematodes, viruses and viroids.

Disorganization and degeneration of vascular tissues coupled with increased chromophily and necrotic obliteration of phloem tissues in RWD affected palms implied the involvement of a phloem limited pathogen in the development of the disease. In 1983, this hypothesis gained experimental support with the

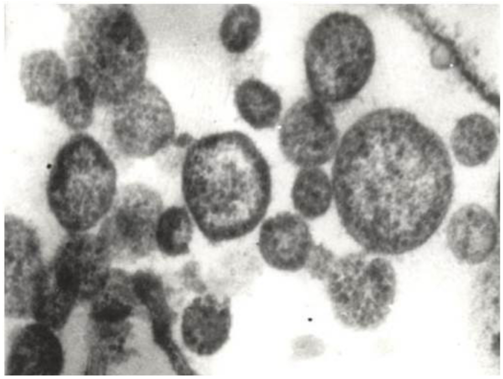


Fig. 2 Electron micrograph showing phytoplasma in the sieve tubes of phloem in diseased palm

electron microscopic (EM) observation of phytoplasma in the sieve tubes of root, tender stem, petiole and developing leaf bases of RWD affected palms (Fig. 2). Phytoplasmas are phloem-limited wall-less bacteria belonging to the class *Mollicutes*. EM studies revealed the uneven distribution of phytoplasma in vascular tissues. They have been found in higher numbers in the sink region notably the heart tissues, rachilla of developing inflorescence and root tissues. Through EM, the RWD phytoplasma appeared as coccoid forms in the size range of 250-400nm. Abnormal bluish colouration in sieve tubes of diseased palms following Diene's staining and increased fluorescence in sieve area consequent to DAPI staining added further evidences to the association of a phytoplasma with the disease.

Phytoplasmal diseases are usually transmitted by insects. The successful transmission of the disease by the two vectors lace bug (*Stephanitis typica*) and plant hopper (*Proutista moesta*) under insect proof conditions and the EM observation of phytoplasma in salivary glands of the identified vectors after an acquisition feeding of 3-4 weeks on RWD affected palms supported the phytoplasmal etiology. Experimental transmission of phytoplasma from coconut to periwinkle (*Catharanthus roseus*) using *Cassytha filiformis* and the remission of symptoms in oxytetracycline treated palms reinforced the pathogenic role of phytoplasma in coconut root (wilt) disease.

Serodiagnostics

Initial investigations on the development of diagnostic techniques were based on the biochemical tests of altered host metabolisms detectable in the form of either accumulation or depletion of substances consequent to differential enzymatic activity in diseased palms. But these changes can also be induced by other biotic and abiotic stresses. With the establishment of the phytoplasmal etiology more thrust was given on the development of a rapid and reliable diagnostic technique. Intensive research in this field led to the development of standardized protocols for the purification of RWD phytoplasma by percoll double density gradient centrifugation, production of polyclonal antisera specific to coconut RWD phytoplasma and Direct Antigen Coated-Enzyme Linked Immunosorbent Assay (DAC-ELISA) for the detection of RWD phytoplasma even 24 months before symptom manifestation. For the screening of large number of samples the indirect DAC-ELISA has been refined in to a simple and rapid detection technique in which the results could be obtained within 7h. This modified technique is now being used for the routine screening of samples. Spindle leaf samples delivered from State Department of Agriculture are being anlysed through ELISA and disease-free mother palms suitable for seed nut collection are identified.

Molecular detection and characterization

Till 1990s, EM and serology based techniques were used for the detection of phytoplasma in coconut and vectors. With the advent of Polymerase Chain Reaction (PCR) based detection techniques, research work initiated at the institute on the molecular detection and characterization of the phytoplasma associated with RWD. Preliminary attempts made to detect the coconut RWD phytoplasma using 16S rRNA sequence based universal primers failed to give consistent results in direct and nested PCRs. This might be due to the low titre and erratic distribution of phytoplasma in the coconut palm, seasonal fluctuations, presence of phenolic compounds and PCR inhibitory substances in the DNA preparations and changes in the universal primer binding sites.

Molecular detection of phytoplasma associated with RWD was achieved by modification of phytoplasma enrichment technique for DNA extraction by addition of 5% polyvinyl pyrrolidone, designing six highly sensitive primers [1F7 (AGTGCT-TAACACTGTCCTGCTA), 7R3 (TTGTAG-CCCAGATCATAAGGGGCA), 3Fwd (ACCTGCCTTTAAGACGAGGA), 3Rev

(AAAGGAGGTGATCCATCCCCACCT), 7R2 (GACAAGGGTTGCGCTCGTTTT), 5Rev (ACCCCGAGAACGTATTCACCG-CGA)] and semi-nested PCR technique. Immature spindle leaves and midribs have been found to be ideal for DNA extraction. PCR conditions for the custom-designed primers sets were also standardized. The semi-nested primer pair 3Fwd/3Rev–3Fwd/5Rev produced an amplicon of 1.3 kb size. The primer pair 1F7/7R3 semi-nested with 1F7/7R2 amplifies a 493 bp fragment of 16S rRNA region of coconut RWD phytoplasma (Fig. 3).

The RWD phytoplasma 16S rRNA gene shows 99% nucleotide identity with that of sugarcane white leaf (SCWL) phytoplasma (AB052874), sugarcane grassy shoot (SCGS) phytoplasma (DQ459439), arecanut yellow leaf disease (YLD) phytoplasma (JN967909), napier grass stunt (NGS) phytoplasma (AY736374), and Iran bermuda grass white leaf (BGWL) phytoplasma (EF444485). Moreover, the RWD phytoplasma 16S rRNA gene sequence (GenBank Acc. No. JX273772) shares 97.7% nucleotide identity with the '*Ca*. Phytoplasma *oryzae*' reference strain (GenBank Acc. No. D12581) and 97.9%

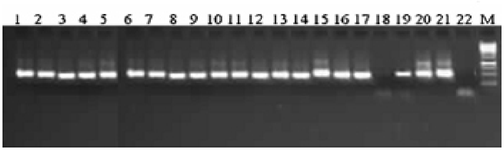


Fig. 3 Detection of RWD phytoplasma with semi-nested PCR IF7/7R3-IF7/7R2. Lanes 1-5: samples from Kasaragod. Lanes 6-20: samples from Kayamkulam. Lane 21: positive control (sugarcane grassy shoot). Lane 22: asymptomatic palm from Kayamkulam. Lane M: 1-kb ladder

nucleotide identity with '*Ca*. Phytoplasma *cynodontis*' reference strain (GenBank Acc. No. AJ550984).

In the phylogenetic analysis based on 16S rRNA gene (F2nR2 region), the RWD phytoplasma clustered with the rice yellow dwarf (RYD) and BGWL group phytoplasmas. However, in the sub cluster, the RWD phytoplasma grouped with the SCWL, arecanut YLD and SCGS phytoplasmas, all belonging to the RYD group (Fig. 4a). For finer differentiation, the *sec A* gene based phylogeny was also considered. The RWD phytoplasma clearly clustered with the YLD, NGS, and SCGS phytoplasma, all belonging to the RYD group (Fig. 4b). Hence, the coconut RWD phytoplasma belongs to the RYD group identified as '*Ca*. Phytoplasma *oryzae*'-related strain.

Further, *in silico* restriction digestion study of phytoplasmal 16S rRNA gene region between primers R16F2n/R16R2 produced restriction profile identical to 16SrXI-B sub group. This formed the first report of the association of 16SrXI-B phytoplasma with coconut in the world. The RFLP profile of *potC* gene of ABC type spermidine/putrescine transport system for RWD phytoplasma has also been found in tune with the 16S rRNA gene based RFLP grouping.

SYBR Green-based real-time PCR assay using the specific primer pair F1 (CGTCTAAGGTAGGGTCGATGA)/R1 (GGACTTGAACCACCGACCTC) which amplifies a 218 bp fragment has also been developed for quick detection of

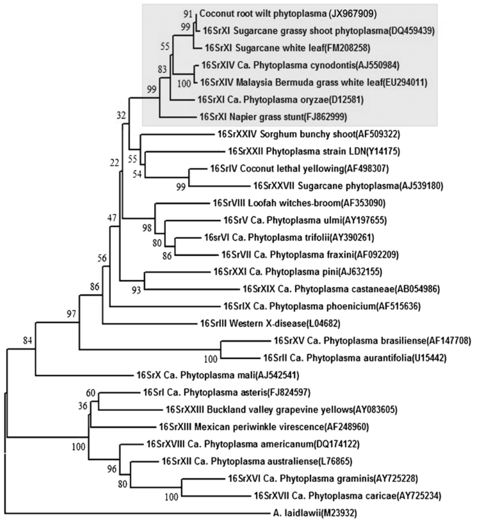


Fig. 4a Phylogram constructed by neighbour-joining method using Mega software based on 16S rRNA gene sequences and *A. laidlawii* as an out group.

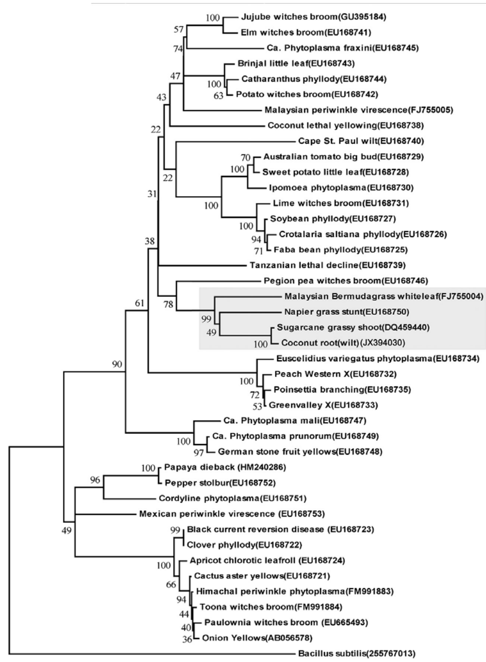


Fig.4b Phylogram constructed based on *secA* gene sequences and *B. subtilis* as an out group.

phytoplasma in RWD affected coconut palms.

Though nested PCR-based amplification of 16S rRNA and further RFLP analysis of the amplified product has revealed the identity of the RWD phytoplasma, subsequent experiments carried out in the recent years using large number of diseased palm samples and insect vectors offered with acquisition access and incubation period (AAP) have shown that the protocol is inconsistent in the detection of RWD phytoplasma. Low concentration and uneven distribution of phytoplasma in the coconut palm may be hindering the use of nested / real-time PCR for routine detection of phytoplasma in the coconut palms and hence the current research is focused on the development of robust diagnostic tools for early detection of RWD in coconut palms.

Insect transmission of RWD

In nature, most of the insect-transmissible pathogens are carried by specific insect vectors and not by other insects, even if they are closely related. Therefore, the scale of damage caused by a pathogen is determined largely by the number of insect-vector species that are capable of transmitting the pathogen. Phytoplasmas propagate within the cytoplasm of both insects and plants.

Mechanism of transmission

Three known mechanisms introduce phytoplasmas into the vulnerable tissues of host plants

a) Vegetative propagation or grafting of infected plant material.

b) Vascular connection made between infected and non-infected host plants by parasitic plants such as dodder (*Cuscuta* spp.)

c) Insect vectors feeding on non-infected host plants.

Recently seed transmission has been reported as the fourth possible source of phytoplasma transmission. Because phloem sieve elements lack any direct connection to seeds, this form of transmission was assumed unlikely, however, lethal yellows phytoplasma has been detected in coconut fruit embryos from infected trees and alfalfa witches broom detected in alfalfa seeds from phytoplasma-infected parent plants.

Taxonomy of vectors

The single most successful order of insect phytoplasma vectors is the Hemiptera. They are efficient vectors of phytoplasma because

a) They are hemimetabolous, nymphs and adults feed similarly and are in the same physical location often both immatures and adults transmit phytoplasma.

b) They feed specifically and selectively in phloem cells, and phytoplasmas are propagative and persistent in them. Their feeding is non-destructive, promoting successful inoculation of the plant vascular system without damaging conductive tissues and eliciting defensive responses

c) They have propagative and persistent relationship with phytoplasmas.

d) They have obligate symbiotic prokaryotes that are passed on to the offspring by transovarial transmission, a similar mechanism that do allow transovarial transmission of phytoplasma.

Phytoplasmas are phloem limited; therefore, only phloem feeding insects can potentially transmit the pathogen. The superfamily containing the largest number of vector species is the Membracoidea which included Cicadellidae (largest group) and Fulgomorpha, in which four families of vector species are found. Most phytoplasma vectors are members of Cicadellidae, however, this is one of the largest insect families, with 25,000 species and taxonomic relationships of subfamilies and tribes are not at all clear. The smallest suborder is Sternorrhyncha in which two genera in the Psyllidae are confirmed vectors.

It was once believed that, for an insect to transmit phytoplasma, it must feed in the phloem in a non-destructive manner, but there are heteropteran vectors that have a more destructive feeding pattern. Two heteropteran families, Pentatomidae and Tingidae, have confirmed vector species. Adults and nymphs of the brown marmorated stink bug, *Halyomorpha halys* Stal. can transmit witches broom phytoplasma to *Paulownia* spp. trees in Asia. The tingid *Stephanitis typica* (Distant) transmits coconut root (wilt) disease in Southeast Asia.

Epidemiology

Epidemiological investigations on root (wilt) disease revealed that the spread was erratic and irregular irrespective of soil conditions and occurred in jumps / leaps. The rate of spread was 1-4 km from the nearest source of infection. The pattern of spatial distribution or galaxial outbreak of the disease was suggestive of the involvement of aerial vector(s) in the spread of the disease. Experimental transmission studies conducted in the past proved the transmission of the disease through the lace bug, *Stephanitis typica* (Distant) [Tingidae : Heteroptera] in the field and in the insect proof house (Fig. 5a). A systematic inventory of insects in root (wilt) prevalent gardens was made using various traps *viz.*, rotary trap, suction trap, light trap and sticky traps and confirmation of their occurrence in coconut foliage by direct examination of 500 young coconut seedlings over a period of two years. In this investigation, besides lace bug, a leaf hopper, *Sophonia greeni* (Distant) and a plant hopper, *Proutista moesta* (Westwood) were recorded (Fig 5b).

a. *Stephanitis typica* b. *Proutista moesta*

Fig. 5 Insect vectors of root (wilt) disease of coconut

Bionomics of insect vectors

The lace bug breeds on coconut foliage feeds from undersurface on the mature leaves in a destructive manner. Stylet course studies revealed that the lace bug inserts its stylet through stomata and ruptures the walls of the cells traversed in the course to reach the vascular bundles. The stylet tip in such cases terminates in phloem thereby suggesting the ability of the bug to acquire the phloem bound phytoplasmas.

The planthopper *P. moesta* breeds in decaying organic matter in the soil and only adult insects are seen feeding on the leaves of coconut palm. The planthopper, *P. moesta* and leaf hopper, *S. greeni* are phloem feeders in a non-destructive manner. The feeding of the former species in coconut is confined to the leaflets of middle and outer whorls while the latter species prefers tender fronds of coconut. Both these insects suck sap from the abaxial surface of leaflets and no feeding marks were observed in leaflets due to their feeding. Absence of honey dew, presence of stylet sheath and permeable mid gut for traversing phytoplasma attribute for good vectoral ability.

Acquisition and transmission studies with insect vectors

Phloem feeding insects acquire phytoplasmas passively during feeding in the phloem of infected plants. When acquired by the insect vectors from plants, phytoplasmas will have to attach to the membranes of midgut epithelial cells, and also need to effectively cross midgut barrier. To be transmitted to plants, phytoplasmas must penetrate specific cells of the salivary glands and high levels must accumulate in the posterior acinar cells of the salivary gland before they are transmitted. In plants, symptoms can develop at 7 days after introduction of the phytoplasma by the insect vector, but can take much longer (6-24 months) depending on the phytoplasma and plant species.

Investigations on these putative vectors revealed the presence of phytoplasma in the salivary glands of *S. typica* and *P. moesta* which were given specific acquisition access and incubation periods but no conclusive lead could be obtained with leaf hopper *S. greeni*. Electron microscopic studies revealed the presence of phytoplasma in salivary glands of lace bugs which were given acquisition access and incubation period ranging from 18-23 days and in plant hopper with AAP of 30 days and more.

The vector role of these two insects was proved experimentally on coconut seedlings kept under insect proof conditions. The lace bug inoculated seedlings showed the presence of phytoplasma between 9 and 27 months after first inoculation and by 17th month after inoculation, 50% of the inoculated seedlings showed flaccidity, the diagonostic symptom of the disease. In the case of plant hopper, 6/8 inoculated seedlings showed the presence of phytoplasma in 5-24 months after first inoculation and five of the seedlings exhibited flaccidity symptom confirming the transmission of the disease.

Vector control studies with regular spraying of insecticides on experimental seedlings could neither prevent fresh incidence of disease nor spread of disease to new plantings, though reduction in population of vectors could be obtained. Successful transmission of phytoplasma from diseased coconut seedlings to periwinkle (*Catharanthus roseus*), a known phytoplasmal indicator host plant could be obtained using the dodder, *Cassytha filiformis*.

These experiemtal results unequivocally proved constant association of phytoplasma in root (wilt) disease of coconut and transmitted by lace bug, *S.typica* and *P. moesta* through EM and transmission studies. However, molecular detection of phytoplasma using universal and custom-designed primers from these two insect vectors was not successful.

Molecular detection of phytoplasma from weeds in coconut plantation

Weeds are potential reservoir of phytoplasmas. Hence, predominant weeds in the RWD-endemic region were carefully examined for the presence of phytoplasma-induced symptoms so as to determine the occurrence of any linking factor with coconut RWD. Random occurrence of phyllody was observed in *Pedalium murex* Linn., (Fig.6a) the weed commonly prevalent in coconut ecosystem of Onnattukara region of Kerala. Typical transformation of floral structures into vegetative parts was recorded. Molecular detection of *P. murex*

a. *Pedalium murex* (Healthy & diseased)

b. *Urochloa distachya* (Diseased & healthy)

c. *Cleome* sp. (Healthy & diseased)

d. *Mollugo* sp. (Healthy & diseased)

Fig. 6 Weeds with typical symptoms of phytoplasma infection

with characteristic phyllody symptoms using universal primers P1/P6 nested with R16F2n/R16R2 revealed amplification for phytoplasma at 1250 bp level. Nucleotide sequence of the amplicon (Genbank accession number: KJ584566) showed 99% homology with sesamum phyllody phytoplasma. This is the first report of molecular characterization of phytoplasma associated with *P. murex* from India.

Furthermore, *Urochloa distachya* white leaf samples (Fig.6b) when subjected to PCR analysis using P1/P6 nested with R16F2n/R16R2 revealed amplification for phytoplasma at 1250 bp level. Nucleotide sequence of the amplicon (Genbank accession number: KJ632690) showed 99% homology with *U. distachya* grass white leaf phytoplasma and *Candidatus* phytoplasma *cynodontis* white leaf. This is the first report of phytoplasma associated with *U. distachya* from India.

The phytoplasma causing *P. murex* phyllody as well as *U. distachya* whiteleaf is identified as ''*Candidatus* phytoplasma *australasiae*"-related strain belonging to subgroup 16SrII-A and ''*Candidatus* phytoplasma *cynodontis*" related strain

a. *Nisea nervosa* b. *Maiestas dorsalis* c. *Oliarus* sp. d. *Orosius albicinctus*

Fig. 7 Auchenorrhynchan fauna associated with weeds in coconut plantation

belonging to subgroup 16SrXIVA, respectively. Furthermore phytoplasma was detectable in weeds such as *Cleome* sp., (Fig. 6c) *Mollugo* sp. (Fig. 6d) *Melochia* sp. and *Sesamum* sp. with typical phytoplasma disease symptoms. It is thus concluded that coconut RWD phytoplasma is not related to *P. murex* phyllody phytoplasma as well as *U. distachya* white leaf phytoplasma due to distant phylogenetic link as established through characterization of phytoplasma subgroups between them.

Auchenorrhynchan fauna associated with weeds in coconut plantation and molecular detection of phytoplasma

Predominant auchenorrhynchan fauna associated with weeds in coconut plantation as revealed from light trap catches are the plant hopper, *Nisea nervosa* (Fig. 7a), the leaf hopper, *Orosius albicinctus*, the zigzag leaf hopper, *Maiestas dorsalis* (Fig. 7b), the agallini hopper, *Austroagallia* sp. and the cixiid hopper, *Oliarus* sp. (Fig 7c). Seasonal diversity existed among these hoppers. While *N. nervosa* was encountered throughout the year, *O. albicinctus* (Fig. 7d) and *M. dorsalis* were intercepted during summer period (March-May). *Austroagallia* sp. and *Oliarus* sp. were recorded during monsoon season.

When these homopteran insects encountered in light trap catches were subjected to molecular detection studies using phytoplasma-specific primers (P1/P7 nested with IF7/7R2), phytoplasma could be detected in *N. nervosa*, *O. albicinctus* and *M. dorsalis* (Fig. 8).

Sequencing of PCR products revealed the occurrence of sesamum phyllody phytoplasma in *O. albicinctus* and molecular characterization of phytoplasma in other auchenorrhynchan fauna associated with weeds in coconut plantation is in progress for understanding phytoplasma-vector relationship.

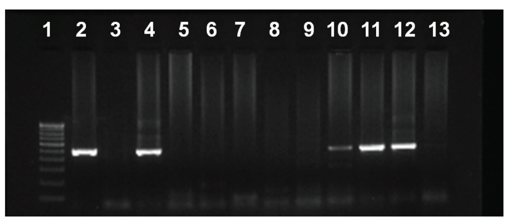


Fig 8. Molecular detection of phytoplasma in auchenorrhynchan fauna Lane 1: 100 bp DNA ladder, 2: Grassy shoot disease of sugarcane, 3: *P. moesta* (AAP >30days), 4&13:*N.nervosa*, 5,7,11,12: O. *albicinctus*, 6: *E. indicus*, 8-10: *Maiestas dorsalis*

Host-plant resistance in coconut

Identification of coconut varieties/hybrids resistant/tolerant to root (wilt) disease was initiated as early as 1953 when the occurrence of healthy and high yielding palms in the midst of heavily disease-affected palms was reported. Selection of such palms for breeding for resistance to root (wilt) disease was emphasized from that period onwards. Screening of available coconut germplasm by planting seedlings in the disease-affected farm at ICAR-CPCRI, Regional Station, Kayamkulam was initiated during 1961. Results of large scale screening trials undertaken during 1972 at ICAR-CPCRI, Regional Station, Kayamkulam and also in cultivator's gardens revealed that all the cultivars and hybrids evaluated contracted the disease. It was then suggested to take up planting of Malayan Dwarfs in root (wilt) affected areas, since it was reported to be tolerant to lethal yellowing disease in Jamaica. In 1982, a trial involving 27 cultivars, 10 hybrid combinations, F2 (OP) of D x T, and progenies of elite WCT palms was laid out in cultivators' gardens. The results revealed that among the 27 cultivars all except Kenthali Orange Dwarf had taken up the disease.

Background of 'hotspot' breeding programme

Based on the recommendations of the First International Symposium on Coconut Research & Development (ISOCRAD-I) held at ICAR-CPCRI, Kasaragod during 27-31st December 1976, a survey of natural population in root (wilt) disease affected areas was conducted during the period 1977-1981 to identify elite super palms exhibiting high yielding potential. A total of 12 elite palms were selected from the root (wilt) affected areas of Kollam, Alappuzha and Kottayam districts. Open pollinated seedlings from these palms were raised and planted in root (wilt) disease affected areas. But all of them took up the disease in subsequent years.

With this background a group meeting was organized at ICAR-CPCRI, Kasaragod during April 1988 and subsequently a comprehensive breeding programme for evolving resistant/tolerant coconut varieties has been implemented at ICAR-CPCRI, Regional Station, Kayamkulam. In an intensive survey in the disease hotspots of Alappuzha, Pathanamthitta, Kollam and Kottayam, 200 CGD palms were observed. It was found that 75% of them were disease-free indicating that this variety possessed higher level of resistance to root (wilt) disease compared to other varieties. It was also observed

Fig. 9. Healthy palm in disease hotspots

that in the disease endemic areas of Kottayam, Alappuzha, Kollam and Pathanamthitta districts, in the midst of heavily disease affected palms, disease-free and high yielding WCT palms were found and these palms were identified as the base material for the breeding programme (Fig.9).

Evaluation of tall progenies for resistance to root (wilt) disease

(i) Evaluation of WCT x WCT crosses

Progenies belonging to the following crosses of WCT were evaluated for root (wilt) disease resistance.

1. WCT x WCT (*Inter se*)
2. WCT (Self)
3. WCT (Mixed Pollen)
4. WCT (Open Pollinated)

All the seedlings were planted during 1992. Observations on disease incidence were recorded as and when the experimental palms developed initial symptoms of the disease. Initial symptoms of the disease *viz*., flaccidity of the young leaves started appearing four years after planting in all the cross combinations of WCT. Observations recorded twelve years after planting revealed that the disease incidence in the progenies raised from various cross combinations of WCT (*inter se* / self / mixed pollen) varied from 55.0% to 58.7%, indicating that there was no significant variation in the susceptibility to the disease among the different cross combinations of WCT. In the case of the open pollinated progenies of WCT there was 80% disease incidence. This showed the superiority of the artificially pollinated seedlings (full sibs) over the open pollinated seedlings (half sibs) with regard to their resistance to the disease. Studies on annual progression of disease incidence over the years indicated that the disease progression was similar in different crosses of WCT. Information regarding the disease incidence among the seedlings produced from disease-free mother palms will be of great use to farmers. Since the artificially pollinated seedlings are clearly superior to open pollinated seedlings with regard to disease resistance as established in the study, they are suitable especially for planting as parental materials in seed gardens.

Further, observations recorded after 18-19 years of planting revealed that the *inter se* mated progenies recorded 35-40% higher nut yield compared to selfed progenies and were also superior with regard to nut characters. A total of 40 high yielding and disease-free palms belonging to the first generation were selected during 2009-10 to produce the second generation progenies for further evaluation, selection and crossing. Analysis of population structure of the mother palms and first generation progenies using SSR markers indicated higher values for inbreeding co-efficient and homozygozity in subsequent generations. Studies revealed that the *inter se* mated progenies were superior to selfed progenies with respect to nut yield and resistance to root (wilt) disease.

(ii) Recurrent selection programme

Crossing programme for developing an improved WCT variety, by *inter se* mating/selfing of selected disease-free WCT palms was initiated during 1991-92. A total of 1250 selfed/ *inter se* mated progenies of disease-free mother palms were planted during 1994-96 at ICAR-CPCRI, Regional Station, Kayamkulam. Selections were made within the progenies. Initially, a total of 80 disease-fee progenies were selected based on visual appearance (disease-free nature) and finally 40 selfed/ *inter se* mated progenies were selected after confirmation by ELISA test. Subsequently crossing programme was carried out during 2010-11 on 40 selected palms for producing second generation selfed /*inter se* progenies. A total of 172 progenies (second generation) have been planted for further evaluation to develop an improved WCT variety with high level of resistance and higher yield.

Varieties / hybrid released

Systematic evaluation trials at ICAR-CPCRI, Regional Station, Kayamkulam for developing varieties with resistance/ tolerance to root (wilt) disease has led to the release of three coconut varieties for the root (wilt) disease prevalent tract. The details of the varieties including one hybrid released are listed below.

Kalparaksha (Selection from Malayan Green Dwarf): This variety was identified as resistant to root (wilt) disease only during 2004. Kalparaksha yields 88 nuts/palm/year with 2.85 t/ha of copra and oil yield of 1.85 t/ha. It is remarkable not only for its high yield but also suitable as a tender nut variety. It has got more quantity of tender nut water (275 ml per nut) which is sweet and tasty. Kalparaksha was released as a resistant variety to coconut root (wilt) disease by Central Variety Release Committee during July 2008 (Fig.10a)

Kalpasree (Selection from Chowghat Green Dwarf): This is comparatively short statured among all dwarf varieties of coconut. In an intensive survey carried out in 'hot spots' of root (wilt) disease, it was found that 75% of CGD palms were disease-free, whereas, the WCT palms standing in the same plots had disease incidence to the extent of 80% or more indicating that CGD variety has higher level of resistance to coconut root (wilt) compared to WCT. Besides, systematic screening trial also indicated that CGD palms are having higher level of resistance to the disease when compared to the other varieties. Kalpasree yields 55 nuts/palm/ year, producing copra yield of 0.94 t/ha and oil yield of 0.55 t/ ha. The kernel has good cooking qualities and oil content of 66.3%. Tender nut water (172 ml per nut) is also sweet and tasty. It is more suitable for cultivation in homestead gardens. But the major disadvantages of this variety are small size of the nut and less copra content. However, like other dwarfs, caution is advised for the control of red palm weevil. Kalpasree was released as a variety suitable for cultivation in the root (wilt) disease prevalent tracts by


a. Kalparaksha


b. Kalpasree


c. Kalpa Sankara

Fig. 10 RWD resistant / tolerant varieties / hybrid released from ICAR-CPCRI

the Central Variety Release Committee during March 2012 (Fig 10b).

Kalpa Sankara (CGD X WCT): This hybrid attains a height of around 3.80 m at 13 years of age. It is early flowering (four years after planting) in nature. The hybrid palms gave a ten year average yield of 84 nuts/palm/year, copra yield of 2.50 t/ha and oil yield of 1.69 t/ha. Though, after 18 years of planting, 67.7 % of these hybrids showed symptoms of root (wilt) disease, the disease-free hybrids gave an average yield of 107 nuts/palm/year, whereas, the disease-affected hybrids gave only 72 nuts/palm/year. With regard to the resistance to root (wilt) disease, hybrid palms were intermediate between parental varieties (CGD and WCT). Tender nut water (373 ml per nut) is sweet in taste. This variety was released for cultivation in the root (wilt) prevalent tracts by the Central Variety Release Committee during March 2012 (Fig. 10c)

Establishment of seed gardens

Apart from breeding for resistance/ tolerance to root (wilt) disease, efforts were made for establishing nucleus seed gardens in the four disease-endemic districts for distributing quality planting materials of WCT, CGD, COD, CGD X WCT and COD x WCT hybrids (depending on demand) to the farmers. Starting from 1995, a total of 4175 artificially pollinated seedlings were so far planted in the five nucleus seed gardens. This includes, 1936 at District Agricultural Farm-Mavelikkara (Alappuzha), 1190 at CPCRI - Kannara (Thrissur), 647 at Coconut Development Board Farm- Neriamangalam (Ernakulam) and 402 at State Coconut Nursery-Karunagappally (Kollam). These seed gardens are presently being maintained by Department of Agriculture (Govt. of Kerala) and Coconut Development Board (Govt. of India).

Characterization of local ecotypes in the disease prevalent tract

Three communities *viz.*, Pathiyoor and Devikulangara (Alappuzha District) and Thodiyoor (Kollam District) in Kerala State were selected and a survey was conducted with the participation of stakeholders, to characterize the local coconut ecotypes. Six ecotypes including four talls and two dwarfs were identified and morphological data revealed that the local ecotype 'Jappanan' closely resembled Evoor

Green Tall ecotype. Simple Sequence Repeat (SSR) analysis was conducted to study the pattern of diversity in 90 selected coconut palms representing the six ecotypes (excluding hybrids) using 14 markers. The observed heterozygosity was much higher in tall ecotypes (0.38-0.45) compared to the dwarf ecotypes (0.03-0.04). Molecular characterization has also helped to identify the most diverse coconut ecotypes which have practical application in production of vigorous hybrids. In the dendrogram constructed using nut character data, three of the tall ecotypes (Green Tall, Brown Tall and Brick Red Tall) clustered together whereas 'Jappanan' clustered separately.

Application of molecular markers in resistance breeding

(i) Molecular markers for tagging genes imparting resistance to coconut root (wilt) disease

The Biotechnology Group at ICAR-CPCRI, Kasaragod have standardized the AFLP, SSR and DAF protocols for tagging gene(s) imparting resistance to coconut root (wilt) disease. The population structure and genetic relatedness among root (wilt) disease resistant and susceptible West Coast Tall coconut palms were analyzed using microsatellite markers. The analysis of genetic relatedness between the resistant mother palms showed that most of the palms located in a single locality shared sib relationship among them. The existence of close genetic relationship among resistant palms from Chengannur, Thiruvalla, Kottayam and Pavukkara localities in Kerala has been reported.

Molecular analysis using microsatellite markers have also been conducted to study the genetic uniformity of Kalpasree and Kalparaksha populations. Forty-two Kalpasree palms from 'disease hot spots' have been analyzed using 43 SSR primers. Monomorphic bands were detected in all the Kalpasree samples with 41 primers. A single Kalpasree palm showed polymorphism with two SSR primers. Forty eight Kalparaksha palms (17 from Seed Garden Complex, Munderi and 31 palms from DSP Farm, Neriamangalam) were analyzed using 24 SSR primers. The Kalparaksha palms clustered at 60% similarity

(ii) Genetic purity assessment of D x T hybrids using microsatellite markers

'Kalpa Sankara' hybrid notified for cultivation in the disease-prevalent tract is produced by hybridizing Chowghat Green Dwarf (CGD) with pollen collected from disease-free West Coast Tall (WCT) palms located in the 'hotspots' of root (wilt) disease. Identification of genuine hybrids in the nursery stage is the most difficult task in hybrid production. A set of 50 hyper-polymorphic coconut SSR markers were used to characterize CGD and WCT parental lines used for hybrid coconut production. From these SSRs, a panel of 17 informative SSR markers capable of distinguishing these parental lines was identified and these markers have been utilized in D x T hybrid seedling purity assessments in coconut nurseries.

Management of root (wilt) disease of coconut

I Phytosanitation

Farm and palm hygiene are two critical factors that reduce the pathogenic inoculum in a coconut garden. While farm cleanliness suppresses build up of pathogen, palm sanitation improves the health status of palm. Eradication and complete destruction of symptomatic-diseased palms in mildly-affected areas as well as emerging disease zones is to be done to reduce the field inoculums. Juvenile palms with symptoms of RWD, irrespective of its intensity, should be removed and destroyed. All disease advanced and uneconomic palms with an annual yield of less than 10 nuts are to be removed for optimum resource utilization and efficiency (Fig.11).

Fig.11 Disease advanced and uneconomic palms for roguing

II Rejuvenation

In endemic zones where the disease inoculums are relatively high and persistent, coconut cultivars that are resistant / tolerant to root (wilt) disease is to be used. High-yielding varieties from root (wilt) disease free zones are not recommended to be introduced in disease hot spots. Hence, replanting should be preferably undertaken with RWD resistant varieties released by ICAR-CPCRI *viz.*, Kalpasree, Kalparaksha or tolerant hybrid 'Kalpa Sankara' in endemic zones. In addition, elite seedlings produced from high yielding and disease-free WCT palms located in the midst of heavily RWD affected palms can also be used in place of seedlings of healthy mother palms located in RWD-free zones.

III Selection of disease free mother palms

Being a long duration-perennial crop, selection of an inferior genotype could substantially reduce the production level of palms, whereas, superior, high-yielding and disease-free palms could produce high quality progenies in coconut. High yielding and disease-free palms showing typical characters are to be selected as mother palms based on plant, reproductive and fruit characters. The age of dwarf parental palms should be 20 years and above and in case of palms of known parentage, the age can be 10 years and above. In gardens planted with large number of dwarfs, mother palm selection should be restricted to 10-20% of high yielding and regular bearing palms.

IV Selection of seedlings

Seedlings that emerge early from the seed nut and growing robustly with higher collar girth and splitted leaves are to be

Fig.12 Good quality seedlings of disease resistant varieties

selected for early and uniform bearing in the main field (Fig.12). In order to ensure eradication of the disease in a phased manner, seedlings showing typical characters (based on DUS protocol) of the recommended varieties alone are to be used for planting.

V Bio-priming of seedlings

Bio-priming of seedlings with bio-inoculants such as *Pseudomonas fluorescens* imparts tolerance to disease as well as promotes better seedling growth. Initial establishment of such seedlings was found to be superior in the main field with enhanced growth and field tolerance to diseases. Application of talc-based preparation of *P. fluorescens* @ 50 g (10^8 cfu/g) per seedling during four, seven and ten months after sowing in nursery is recommended. At the time of planting in the main field, dip coconut seedlings in 100 g (10^8 cfu/g) of talc-based preparation of *P. fluorescens* in slurry-mode.

VI Application of organic manures

A good organic base in soil is very important for the improvement of physical, chemical and biological properties of soil as well as for enhanced availability of nutrients. Organic manuring also enhances the beneficial microbial load in the soil and favour better availability of other nutrients and bioenzymes for palm growth. With heavy rainfall experienced in most of the coconut growing regions, sizeable quantity of the essential nutrients are leached off in the absence of good organic matter. Application of 25 kg farm yard manure or 10 kg of vermicompost enriched with *Trichoderma harzianum* @ 100 g is recommended for the RWD affected gardens.

VII *In situ* biomass recycling

Growing leguminous green manure crops such as *Peuraria phaseoloides* / *Vigna unguiculata* (cowpea) @ 100 g in palm basins during April–May and September–October and incorporating

Fig. 13 Leguminous green manure crops in palm basin for *in situ* biomass recycling

the biomass at flower initiation stage not only fixes atmospheric nitrogen but also enhances the C:N ratio for better palm growth (Fig.13). It was also found to reduce the intensity of RWD and substantially increase in nut yield through better availability of other nutrients with improved soil aeration. Growing glyricidia along the border and periodical pruning and incorporation into the palm basin is also advised.

VIII Application of fertilizers

Coconut palm requires good quantum of primary, secondary and micronutrients for the sustained growth and production of nuts, nut water *etc*. Maintenance of heavy palm trunk, regular production

Fig.14 Soil test-based fertilizer application

of fronds, root regeneration *etc*. demand continuous supply of nutrients, irrespective of season. Soil-test based application of NPK fertilizers (500g N, 300 g P_2O_5, 1250 g, K_2O and 250 g $MgSO_4$/palm /year) in two splits during May-June and August-September is recommended (Fig.14). Juvenile palms should be provided with 1/10, 1/3, 2/3 dose of NPK during the first three years of planting in the main field. Judicious application of micronutrients based on soil analysis and for adult palms, application of borax @ 120 g in four split doses based on the intensity of deficiency symptom is also recommended.

IX Liming of soils

Soils in Kerala are found to be very acidic in nature and deficiencies of Ca and Mg is also well pronounced. Due to the widespread deficiency of these secondary nutrients and enhanced acidity in Kerala soils, application of dolomite @ 1 kg / palm / year is recommended towards ameliorating Ca and Mg deficiency and also for increasing soil *p*H. When application of lime/dolomite is resorted to, it should be supplemented with magnesium sulphate on soil-test basis.

X Soil and water conservation measures

Soil moisture conservation measures such as mulching / husk burial should be undertaken during November to May to conserve soil moisture during summer months and prevent erosion of fertile top soil during monsoon rains (Fig.15). Irrigate the palms during summer months @ 250 l/palm/week to mitigate moisture

Fig. 15 Coconut husk burial in palm basin for moisture conservation

stress as water is very critical for palm growth. Avoid water logging and provide proper drainage wherever necessary so as to ensure soil aeration and root growth.

XI Management of coastal sandy loam soils

Coastal sandy regions are so stressed during monsoon period by the way of leaching away of nutrients and fertile top soil. In addition, inundation of water may also occur in several tracts leading to deficit aeration in soils. These conditions are highly favourable for multiplication of pathogenic organisms. In coastal sandy soils regions with RWD, application of 500 g *T. harzianum* enriched neem cake and incorporation of green leaf manures like glyricidia is recommended.

XII Cropping / farming system approach

Raising different crops in the interspaces ensures effective utilization of natural resources, maximum returns per unit area and provides biomass for recycling. It will not only ensure regular economic returns to the farmers but also provides more employment opportunities for the farm family. Coconut based high-density multispecies cropping system (HDMSCS) can be successfully adopted in RWD affected coconut gardens by raising a combination of suitable crops. HDMSCS and integrated management practices improve coconut yield by 30 to 40% by reducing RWD intensity. HDMSCS will be more successful in places with irrigation facilities and Perfo method is the most ideal system of irrigation. In such cropping systems, care should be taken to follow the recommended package of practices including adequate manuring for component crops. Cash, food and fodder crops are generally included in the cropping system. The entire biomass can be converted into vermicompost in the coconut garden itself using *Eudrilus* sp. of earthworm and used in the cropping system to partly meet the nutritional requirement of crops. Vermicomposting in synergy with integrated farming system approach would ensure sustained money-flow to the farming community. Adopt cropping system approach by raising intercrops in rotation / adopt mixed cropping /mixed farming with recycling of organic matter for reaping sustainable income (Fig.16). Restructuring of canopy of other perennial tree crops to provide maximum light for the coconut palms is recommended.

Fig. 16 Intercropping for income generation

XIII Management of leaf rot disease

Leaf rot disease, caused by a fungal complex, infects during all the seasons including summer period. Emerging terminal spindle leaves are badly

Fig. 17 Leaf rot management and recovery of spindle leaf

affected with tremendous setback on the photosynthetic efficiency of palms, leading to retardation in growth and nut production. Leaf rot management is, therefore, more crucial in the health improvement of RWD affected palm, as >99% of leaf rot affected palms exhibit symptoms of RWD (Fig. 17). Cut and remove only the leaf rot affected portions of spindle and two top most fully opened leaves to reduce the pathogen level. Apply hexaconazole 5 EC @ 2ml in 300 ml water by dispensing around the base of spindle leaf. Apply talc-based preparation of *P. fluorescens* / *Bacillus subtilis* or consortia of the two bio-agents @ 50 g in 500 ml water/palm. Any one of the above treatments may also be adopted as prophylactic measure during April-May and October-November in RWD-endemic regions. Timely adoption of these technologies through area wide approach would be ideal.

Fig. 18 Prophylactic leaf axil filling with sand and neem cake

XIV Bio-intensive management of rhinoceros beetle

Adopt area wide farmer-participatory integrated approaches for management of rhinoceros beetle. Disposal of breeding grounds and incorporation of *Clerodendron infortunatum* and / or *Metarhizium anisopliae* @ $5x10^{11}$ spores/ m^3 into breeding sites is recommended. Mechanically hook adult beetles from infested palms. Prophylactic leaf axil filling with oil cakes *viz.*, marotti, neem, pongamia (250 g) mixed with equal quantity of river sand or 50 g chlory dust mixed with 2 kg sand for 8 palms or placing naphthalene balls (12 g) is to be taken up (Fig. 18). Placement of two perforated polythene sachets containing chlorantriniprole (3 g) on top most leaf axils in juvenile palms is also recommended as a prophylactic measure. As a bio-control measure, release adult beetles inoculated with *Oryctes rhinoceros* nudivirus (OrNV) @ 10-15 beetles / ha.

Fig. 19 Management of red palm weevil

XV Integrated management of red palm weevil

Red palm weevil is the most destructive and fatal enemy of coconut palm. All the immature stages thrive within the palm and, therefore, it is necessary to adopt holistic management of palms. An integrated management strategy with emphasis on phytosanitation measures, curative management and behavioral manipulations was standardized and field validated. Phytosanitation and timely management of pre-disposing factors such as damage by rhinoceros beetle and leaf rot disease are needed. Avoid injury to palms and take up complete destruction of red palm weevil infested palms in the field. While cutting petioles, leave at least 1.2 m from trunk of palm. Apply imidacloprid (1 ml / l water)) or spinosad (5 ml / l water) as curative treatment of infested palms (Fig. 19). Install pheromone traps with ferrugineol embedded on nanoporous matrix @ one trap / ha. Ensure timely servicing of food baits once in six days and avoid placing traps in gardens with juvenile palms or palms intercropped with tall intercrops (banana).

Technology delivery mechanisms for root (wilt) disease affected areas

Technology delivery to the stakeholders acquires greater importance in case of homestead systems as well in risk prone areas like root (wilt) disease affected coconut areas, where the extension system has to reach out to diverse community of farmers. Research results which are not being used in actual farming situations cannot render the impact or outcomes to productivity or income levels. Hence technology and knowledge delivery/ utilization in case of root (wilt) disease needs social research support to evolve appropriate approaches and strategies for reaching out to coconut communities, providing technology options suiting situations/ resources and disease conditions. ICAR-CPCRI experimented with participatory technology transfer approach (PTTA), coconut clusters in root (wilt) affected areas yielding positive responses and field level impact. But it is imperative to evolve convergence based strategies involving related agencies/ institutions for spatial and community level spread and utilization for managing the disease through Information communication technologies and GIS tools.

Potential of technology based management for root (wilt) disease

The potential productivity of coconut palm to the tune of 3-6 tons of copra per hectare based on the input management could not be achieved so far. It was reported and proved in farmers field also that even in root (wilt) diseased areas the productivity level of 150-200 nuts/ palm/annum could be achieved through upgrading management practices/ technologies.

The root (wilt) disease of coconut is prevalent in all districts of Kerala in varying severity. The extent of incidence was highest in Alappuzha district (48.03%) followed by Pathanamthitta (37.8%), Kottayam (36.5%), Idukki (33.56%), Ernakulam (33%) and Kollam (25.97%). In the districts of Thrissur and Thiruvananthapuram, disease incidence was less than 10%. Research efforts of ICAR-CPCRI have resulted in evolving integrated management technologies which was demonstrated in farmers' fields as participatory programme.

Case study of participatory demonstration of root (wilt) disease management package

The front line demonstration programme was implemented during 1999 – 2003 in an area of 25 ha of contiguously cultivated gardens comprising of 208 farmers with almost 5000 adult palms around the ICAR-CPCRI, Regional Station, Kayamkulam (Fig. 20).

The demonstrated package of technologies resulted in improvement of yield and health of disease affected coconut palms. Significant improvement

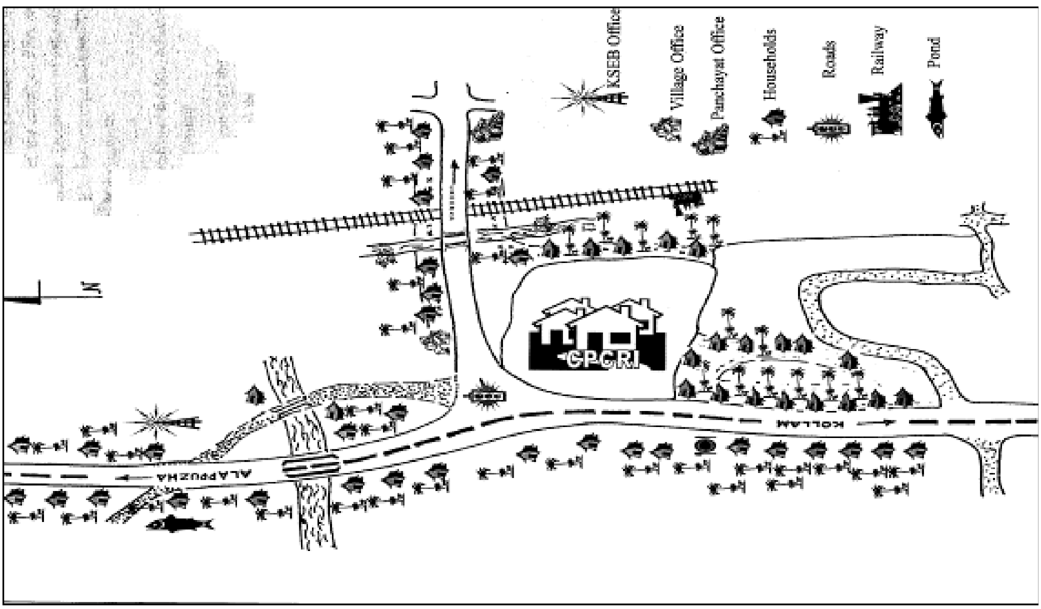
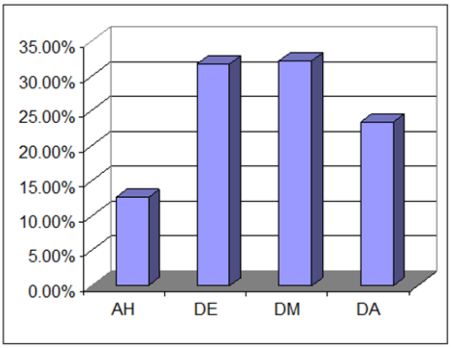
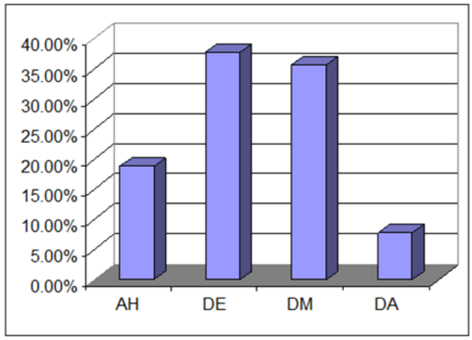


Fig.20 Social map of area under participatory technology transfer approach (PTTA) for root (wilt) disease management

Pre demonstration



Post demonstration



Apparently Healthy	12.6%	Apparently Healthy	18.8%
Disease Early	31.7%	Disease Early	37.7%
Disease Middle	32.2%	Disease Middle	35.7%
Disease Advanced	23.2%	Disease Advanced	7.8%

Fig.21 Impact of management in reduction of severity of root (wilt) disease

of health of palms from disease advanced stage to disease middle or disease early stages of disease after adoption of the management package (Fig. 21). The average yield of coconut in disease tracts improved from 24 to 46 nuts per palm per year, *ie*., 91.4 percent improvement. The B:C ratio improved from 1.03 to 1.77 proving the economic viability of root (wilt) disease management in coconut gardens. The regeneration of root (wilt) disease advanced palms is very difficult and not economical also, hence DA palms with less than 10 nuts yield annually was removed.

The perceptions of the participating farmers in terms of need and usefulness indicated positive responses in most

Table1. Perception of farmers about need and utility of root (wilt) management practices

Sl.No.	Practices	Need (%)*			Useful (%) #		
		3	2	1	3	2	1
1	Leaf rot disease management	40.0	60.0	0	6.6	86.8	6.6
2	Basin management - green manure	73.3	26.7	0	66.7	33.3	0
3	Chemical fertiliser application	46.7	53.3	0	46.7	53.3	0
4	Red palm weevil management	39.9	46.7	13.4	26.7	46.7	26.6
5	Eriophyid mite management	53.3	40.0	6.7	40.0	53.3	6.7

*3-Very much needed. 2-Needed. 1- Not needed #3-Very much useful. 2- Useful. 1- Not useful of the technologies as evident in Table 1. The need and usefulness of leaf rot management, basin management and application of chemical fertilizers perceived by the participated farmers showed their conviction and positive perception of these component technologies in the management of coconut root (wilt) disease.

The perception of the participants about the project implementation reflected their involvement and understanding which was indicated as satisfaction in the component activities of participatory technology transfer approach as furnished in Table 2. The perception items provided the interactive modes adopted and the clarity of participants regarding the networking, knowledge / skill facilitation by researchers and the team effort in field situation.

Impact recorded in Participatory Rural Appraisal (PRA)

- Leaf rot reduced 50-60% completely
- Awareness about the ICAR-CPCRI research findings increased
- More involvement of researchers, farmers and extension officials
- Yield of palms improved more than 60%
- Copra content increased
- Yellowing of palms reduced with greenish appearance of palms
- Exchange of ideas between farmers increased
- General improvement in the health and vigour of palms

It was established that under high density multi-species cropping system in coconut, overall system productivity could be improved by 176%. The environmental benefit in terms of water holding capacity in coconut based farming system was 37.4-38.5% compared to monocrop plot *i.e.* 35.3-35.8%. Addition of green manure (cowpea) in basins, which is a low cost and simple technique increased status of major nutrients in soil.

Participatory Technology Transfer (PTT) in root (wilt) disease affected coconut area

The PTT approach involved research

Table 2. Perception of farmers about implementation of the project

Sl.No	Items	(3)*	(2)*	(1)*
1	Adoption of the recommendations	50	50	0
2	Utility of the training programmes	35.7	28.6	35.7#
3	Co operation/ participation of CPCRI staff	78.5	21.4	0
4	Timely communication of information	71.4	28.6	0
5	Plot visit of the staff	85.7	14.3	0
6	Consideration of farmers' opinion	64.3	35.7	0
7	Field problem solving	71.4	28.6	0
8	Co operation / participation of the farmers	64.3	14.3	21.4

(All values in %) # Not participated *3- Very much satisfactory, 2- Satisfactory, 1- Not satisfactory

Table 3. Impact of Participatory technology transfer (PTT) on awareness, knowledge, attitude and adoption of participated farmers

Variables	Average Scores		't' values
	Before PTT	After PTT	
Awareness	14.11	32.53	14.35*
Knowledge	18.84	59.47	08.05*
Attitude	22.56	36.48	04.38*
Adoption	16.32	45.58	06.89*

*Significant at 0.05 level

groups/ first line extension agencies. Farmers organizations, progressive farmers, local panchayaths and women Self Help Groups (SHG). The major implementation phases were rapport building and stakeholder analysis, deciding the theme, participatory assessment of crop and farming situations/ farmers needs/problems and integrated technology transfer methods, technology implementation, monitoring and regular follow up and participatory evaluation. The PTT components utilized were multi-faceted including scientist farmer interaction meetings (on and off campus), participatory rural appraisal (PRA), result demonstration of root (wilt) disease management package, mass media, individual and group methods/ tools and impact analysis. The impact of the PTT indicated in the improvement in awareness, knowledge, attitude and adoption of root (wilt) management practices as indicated in Table 3.

The participatory technology transfer (PTT) interventions were effective in terms of improvement in awareness and knowledge on symptoms of root (wilt) disease of coconut, knowledge on various items of the disease management components, attitude towards disease management and adoption of practices in terms of symbolic adoption scores. These factors are relevant in the sustainability of technology utilization along with policy implications including market and price levels of inputs and produces.

Table 4 indicated significant impact in terms of management levels in improving yield of palms which is also a pointer towards improvement in health of disease-

Table 4. Improvement of coconut yield in root (wilt) disease affected palms– impact of integrated management package

Mean Yield	Recommended management	Low management management	Average management	F- ratio
Below Fist size	26.42	8.55	20.04	27.38**
Above Fist Size	36.76	17.01	24.89	24.17**
Mean yield	49.97	21.285	34.91	

affected palms. The relative advantage, observability, feasibility and economic viability of the technology package could be achieved by adopting the recommended management practices in the root (wilt) disease affected areas. The potential of the technology in doubling the nut yield was also indicated.

Cluster approach for improving income and productivity of coconut

- Clustering coconut farmers for improving unit area income
- Overcome the problem of fragmented land holdings
- Better platform for technology dissemination
- Involvement of whole farm family for integrated farming
- Integrated farm level processing of coconut and marketing
- Improvement in income by 60%

Impact of coconut-based cropping systems on productivity and economic viability in root (wilt) affected gardens

The cropping system model in one ha area included 112 coconut palms of different age and disease severity, nutmeg (45 nos.), black pepper (30 nos.). banana (poovan, njalipoovan, palayankodan, karpooravalli, nendran –500 nos.), pineapple (3600 nos.), tuber crops (amorphophallus, colocasia, dioscorea- 300 nos.). Cash flow analysis indicated highly positive values with benefit cost ratio of 2.28 showing the economic viability of the system in root (wilt) affected areas. The yield of coconut palms improved from 30 nuts/palm/year to 75.8 nuts/palm/year after 3 three years of integrated management and cropping system adoption indicating 152 per cent improvement in productivity of coconut. Hence, in the farmers gardens also adoption of cropping or farming systems improves the productivity of root (wilt) disease affected coconut palms as well as improves the unit area income.

Strategies for technology delivery for root (wilt) disease areas

The factors to be considered for future strategies are:

- Economies of scale in fragmented holdings of small and marginal coconut farmers
- Perennial nature of the crop determining observability of technology impact
- Risk of fluctuating price, market, global competition
- Value addition gaps in terms of quality production and processing
- Variability in terms of location specificity, root (wilt) disease severity, adoption status of farmers, *etc*

Based on the factors the strategies envisaged are:

1. Spatial analysis and technology

delivery strategies for specific problem domains in root (wilt) disease affected areas in national perspective

2. ICT package for comprehensive and integrated technology assessment, delivery and adaptations for integrated disease management

3. Responsible specific technology transfer and follow-up approaches and action plan for root (wilt) disease affected areas including income generating models for different land holdings

4. Research facilitation and timely responsive support system for farming community of diseased areas

5. Participatory monitoring and impact analysis for communicating research use for policy evolvement

The integrated management strategies supported with specific and appropriate technology delivery approaches could improve the livelihood status and up gradation of research utilization for observable impact in root (wilt) disease affected areas of coconut.

Root (wilt) disease of coconut is still a potential debilitating disease in Kerala and spreading at a slower pace in adjoining states too. Effective management strategies have been evolved to tackle this disease in a farmer-participatory mode by bio-priming of seedlings, systematic nutrition and suppression of leaf rot. Large-scale production of seedlings of resistant / tolerant varieties / hybrid in tune with farmer's demand is needed. Development of robust diagnostic tool for detection of the disease in the early phase helps to formulate and implement most effective management packages. Survival of phytoplasma in weeds and phytoplasma-vector relationship is being attempted. Identification and utilization of plant growth promoting rhizobacteria has been initiated to sustain palm health and deliver economic yield.

भाकृअनुप
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