Breeding for drought tolerance in coconut: Status and potentials

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Scientific and theoretical basis of breeding for drought tolerance in coconut

Water is among the natural resources required for crop production which is becoming scarce everyday. Efficient management of available water is very important for sustainable crop production. Growing cultivars having efficiency in water use is one of the ways in this direction. It is even more important in the case of coconut, a perennial plantation crop, mainly grown under rainfed and marginal conditions and faces annual summer stress.

Productivity of any crop is dependent on the efficiency (i.e., Water Use Efficiency - WUE) of crop in utilizing the available water for biomass production. Therefore, it will be possible to use WUE as a trait for crop improvement programme (Passioura 1977, 1986). Work on drought tolerance in coconut at the Central Plantation Crops Research Institute (CPCRI), Kasaragod indicated variability for WUE, dry matter production and yield in coconut cultivars (Rajagopal *et al.* 1989; Kasturi Bai *et al.* 1996a). Thus, it should be possible to identify high WUE types with a capacity for high biomass production in order to develop water use efficient coconut types, i.e. with drought tolerance and high yield. Research so far on 75 cross combinations, reciprocal crosses, and their parents, which were screened for drought tolerance and revival capacity at CPCRI indicated that in general, Talls and hybrids with Tall as mother palm had higher drought tolerance compared to Dwarfs and hybrid with Dwarf as mother palm. Heterosis was observed for some of the desirable characters for drought tolerance. Earlier studies (Rajagopal *et al.* 2000a) indicated the possibility of exploiting the heterosis of some of drought tolerant traits in evolving drought tolerant hybrids.

How serious is the problem?

Coconut is mainly grown as a rainfed crop and the productivity is about 50% less in these areas than in irrigated gardens. Coconut faces summer dry spells each year apart from the frequent occurrence of drought years. Being perennial in nature, coconut palm had a long duration from the initiation of inflorescence primordia to nut maturity (about 44 months) with longer pre-fertilization period (about 32 months) than post-fertilization (12 months) period. Hence, the impact of drought occurring at any of the critical stages of the development of inflorescence affects nut yield (Rajagopal *et al.* 1996; Rajagopal *et al.* 2000a) not only during the drought year but also in the following three years making the problem more severe (Naresh Kumar 2002). In worst affected conditions, coconut takes at least four years to recover after going through a stress period. In addition, water deficit at early growth stage could lead to seedling mortality. All these factors result in considerable economic loss to the growers. Planting drought tolerant cultivars with faster recovery potential could alleviate much of this problem. Hence, there is an urgent need for cultivars or hybrids with high drought tolerance capacity and stable yields.

Drought stress affects coconut production in almost all countries where it is grown, since it is mainly a rainfed plantation crop. The environmental stresses affected coconut yield (Coomans 1975; Mathes 1988; Bhaskara Rao *et al.* 1991) in intermediate and dry zones of Sri Lanka (Peiris and Peries 1993; Peiris *et al.* 1995; Peiris and Thattil 1998) and in Zanzibar (Juma and Fordham 1998). Bonneau and Subagio (1999) identified the drought-prone zones in coconut growing areas of Indonesia. All these highlight water deficiency as the major constraint for coconut productivity and the need for coordinated effort to identify and develop drought tolerant cultivars/hybrids.

Environmental factors and coconut

The growth and productivity of coconut palms are influenced by external factors such as rainfall, temperature, sunshine duration and relative humidity. The optimum weather conditions for good growth and nut yield in coconut are well-distributed annual rainfall between 130 and 230 cm, mean annual temperature of 27°C, abundant sunlight ranging from 250 to 350 Wm^{-2} with at least 120 hours per month of sunshine period (Child 1974; Murray 1977). The coconut palm experiences moisture stress when exposed to excess radiation above 265 Wm^{-2}, temperature of 33° C and vapour pressure deficit of 26 m bar (Kasturi Bai *et al.* 1988), aggravated by soil water deficit during the period. The duration of dry spell during initiation of inflorescence primordium, ovary development and button size nut stages, in that order, have greater influence on nut yield than other stages (Rajagopal *et al.* 1996).

Depending on the soil type, the critical level of soil moisture that coconut experiences water stress varies considerably. In sandy loam soil, water deficit of 110 mm is critical at which coconut suffers most due to moisture stress as indicated by the stomatal closure (Rajagopal *et al.* 1989). The photosynthetic rates, dry matter production and its partitioning are influenced by the soil water status (Kasturi Bai 1993: Naresh Kumar *et al.* 2002a). In general, palms suffered more in red sandy loam than in laterite soil as indicated by the stomatal resistance and leaf water potential. The soil types and compaction levels influenced the degree of water stress in seedlings also (Nainanayake and Bandara 1998). Hybrids had higher stomatal resistance resulting in maintenance of higher water potentials during stress in laterite soil than in sandy loam (Voleti *et al.* 1993a). However, the hybrid COD x WCT was found to be most sensitive to water stress in sandy loam soil.

Impact of drought stress on coconut

Coconut palm is influenced both by atmospheric and soil droughts as the palms are mainly cultivated on the coastal sandy, red sandy loam and laterite soils. Under rainfed conditions, a prolonged dry spell extending from 3 to 6 months affects the palm. Based on the weekly water deficiency (WD) and weekly water need (WN), Rao (1985) worked out the 'aridity index' (Ia) for assessing drought. Where Ia= WD / WN x 100. An aridity index of 100% for a prolonged period of 5 to 10 weeks drastically affects productivity of coconut palms. When exposed to such severe moisture stress, coconut palms exhibit adverse effects such as bending and breaking of dry leaves, poor spathe development and almost empty bunches. Based on the aridity index, drought classification was made to asses the extent of damage to coconut palms (Table 1).

Table 1. Relationship between aridity index and symptoms of drought in coconut *(Source: Rao 1985)*

Aridity index (%)	Morphological symptoms	Drought intensity
65	Nil	Slight
65-85	Drooping of lower leaves	Moderate
85-100	Beginning of drying of drooped leaves and button shedding.	Moderately severe
100 for five weeks	Drying of drooped leaves, falling of tender and immature nuts; burning trace on nuts due to the high intensity of radiation.	Severe
100 for > 5 weeks	Palms show the death symptoms, drying of the spindle leaf.	Disastrous

On the other hand, Pomier and de Taffin (1982) calculated 'index to drought tolerance' based on the percentage of dry leaves (n), compared to the number of living ones (N) i.e., (n/N)100. This is based on morphological symptoms alone and is related to nut yield. They reported variation in 'drought tolerance index' among five genotypes with the hybrid PB-121 as the most tolerant and Rennell Tall x West African Tall as the most sensitive to drought. The 'drought tolerance index' was the lowest in the hybrids WCT x PHOT and WCT x GBGD and the highest in WCT x MOD (Ramadasan *et al.* 1991). Repellin *et al.* (1994) also placed PB - 121 under drought tolerant group while WAT was classified as moderately tolerant based on a study of the effect of edaphic drought on the leaf water status, gas exchange and membrane lipids at the nursery stage of five coconut varieties. Kasturi Bai *et al.* (2001) reported the extent of variation in physiological characters among the parents and hybrids at the nursery stage. In Sri Lanka, the drought tolerant Tall x Tall palms were selected based on the mean yield and genotypic adaptation to changes in climate over a 15-year period. Characterization of drought in different coconut growing areas in six states of India falling under different agroclimatic zones revealed that the dry spell length and intensity of stress adversely affect the coconut and consequently nut yield (Naresh Kumar *et al.* 2003). In this study, high adverse effect of length of dry-spell on nut yield was noticed up to four years, with more impact during the fourth year. Apart from this, adverse impact on the current year nut yield was also observed.

Physiological responses to drought stress

Coconut palm responds to drought stress by stomatal regulation and deposition of leaf surface wax (ECW) to maintain leaf water potential. Osmotic adjustment, by accumulation of organic solutes, also plays an important role in the drought tolerance mechanism in coconut (Kasturi Bai and Rajagopal 2000).

Stomatal regulation. Seasonal variations in climatic conditions *viz.*, solar radiation, air temperature and relative humidity influence xylem tension by stomatal regulation, a key factor controlling the water balance in coconut (Milburn and Zimmermann 1977; Rajagopal *et al.* 1986). Development of stress was monitored in coconut during wet and dry seasons by estimating stomatal regulation (Kasturi Bai *et al.* 1988; Juma *et al.* 1997), which varied among cultivars (Voleti *et al.* 1993a). The leaf to air vapour pressure deficit (LAVPD) and leaf to air temperature difference (rT) influenced the stomatal conductance (gs) and water relations during day time and thus predominantly determined the variations in photosynthetic efficiency of coconut in irrigated and rainfed conditions (Rajagopal *et al.* 2000b). Jayasekara *et al.* (1993) identified the drought tolerant genotypes based on the stability in physiological parameters viz., transpiration rate, diffusive resistance and leaf water potential during the stress period.

Leaf water potential. Leaf water potential (Ø$_{\text{leaf}}$), an indicator of plant water status, showed a vertical gradation from middle leaf upwards, the magnitude being higher under rainfed condition (Voleti *et al.* 1993b). Seasonal variation among the cultivars for $\varnothing_{leaf}$ was also noted (Voleti *et al.* 1993a; Shivashankar *et al.* 1991). A rapid screening method was developed based on $\varnothing_{leaf}$ in excised leaflets (Rajagopal *et al.* 1988) for easy handling of a large number of genotypes. The $\varnothing_{leaf}$ declined with time to different degrees among the genotypes, indicating the degree of tolerance/susceptibility to stress. These were in conformity with the field-testing conducted for drought tolerance. Passos and da Silva (1991) established the relation between the hydric state of the tree and the diameter of its trunk by dendrometry. From the studies in a group of Dwarf and Tall palms on the root system, stomatal conductance and water potential, it was concluded that the behaviour of palms in drought conditions depends on several factors, *viz.*, water relation components like transpiration, stomatal conductance and leaf water potential as well as agro-meteorological factors like solar radiation, rainfall and humidity, which may interplay to facilitate over all drought tolerance mechanism (Passos and da Silva 1991).

Epicuticular wax (ECW). ECW is one of the important parameters, which influence the energy balance of leaf. In coconut, the ECW on leaves did not differ significantly among cultivars and hybrids under favourable conditions. However, almost three to four fold increases in ECW was noticed during dry season in some of the coconut hybrids *viz.*, WCT x GBGD, WCT X COD, LCT x COD and LCT x GBGD (Voleti and Rajagopal 1991; Kurup *et al.* 1993). The physiological age of palms and of leaves influenced the formation of wax on leaf surface. Leaves of coconut seedlings have almost 50% less ECW than those of adult palms even at the same degree of stress.

Osmotic adjustment. Coconut palms accumulate organic solutes such as sugars and amino acid during stress period. Accumulation of these solutes was more in the tolerant types than the susceptible types during severe stress condition (Kasturi Bai and Rajagopal 2000). This implies that osmotic adjustment plays an important role in the drought tolerance mechanism in coconut.

Root-shoot signals. Roots in drying soil are known to over produce abscisic acid (ABA) thus providing signals to shoot for closure of stomata for water regulation in plant (Zhang and Davies 1989). Root-shoot relationship was also reported to be an effective indicator of soil compaction and water stress for coconut seedlings (Nainanayake *et al.*

2000). High ABA/cytokinin ratio in leaf has positive influence on water use efficiency (WUE), whereas a high ABA/ cytokinin ratio in root has a negative influence on WUE in coconut seedlings (Kasturi Bai 2003).

Biochemical responses to drought stress

The biochemical responses of coconut palm to drought stress include regulation or synthesis of scavenging enzymes to maintain cell membrane integrity thus enabling cells to tolerate stress.

Effect of water deficits on enzyme activity. Concomitant with the decrease in the leaf water status during drought stress, the activities of stress sensitive enzymes differ depending upon the nature and function of the enzyme in question. Drought stress caused an increase in the activities of some of the stress sensitive enzymes viz., peroxidase (PO), polyphenol oxidase (PPO), superoxide dismutase (SOD), acid phosphatase (APh) and L-aspartate: 2-oxoglutarate amino transferase (AAT) in adult WCT palms, while activities of Malic dehydrogenase (MDH) and nitrate reductase (NR) were decreased (Shivashankar *et al.* 1991; Kasturi Bai *et al.* 1996 b, Kasturi Bai *et al.* 2003). Drought tolerant varieties are endowed with a biochemical mechanism in adapting the adverse effects of drought through appropriate regulation of enzyme activities. Many enzymes exist in multiple molecular forms called isozymes and changes in the activity or appearance of isozymes represent the relative tolerance of coconut cultivars to water stress (Shivashankar 1988). Increased intensity of APh isozyme II shows the susceptibility of the genotype to water deficits since APh is a hydrolytic enzyme (Shivashankar and Nagaraja 1996). Two additional fast moving bands of PPO were located in the drought susceptible varieties under stress, while the drought tolerant cultivars showed no change (Shivashankar 1988). The variability in the isozyme patterns of enzymes like esterase, peroxidase, phosphoglucoisomerase, alcohol dehydrogenase, glutamate oxaloacetate transaminase and acid phosphatase were also reported in coconut germplasm (Fernando and Gajanayake 1997).

Membrane stability in relation to drought stress. At the cellular level, the impact of stress is generally seen on the integrity of membranes and extent of solute leakage, which is regulated by the cell membrane stability. Normal cell functions are affected due to changes in peroxidation of cell wall lipids (LP) during stress resulting in increased cell permeability and solute leakage. In coconut, lipid peroxidation was high in drought susceptible cultivars as compared to tolerant ones (Chempakam *et al.* 1993). Drought tolerance is thus characterized by higher activities of the protective enzymes like SOD, catalase and peroxidase and consequently coupled with lower levels of lipid peroxidation and higher membrane integrity. Coconut seedlings of the tolerant group maintained lower water loss and lipid peroxidation than the susceptible group and a negative correlation between leaf water potential and lipid peroxidation was observed (Kasturi Bai *et al.* 2001). Repellin *et al.* (1997) observed marked reduction in total leaf lipid and chloroplastic major lipid (monogalactosyl diacylglycerol) contents in drought susceptible cultivars.

Role of K^+ and Cl^- nutrition in relation to drought tolerance in coconut

The role of K^+ and Cl^- nutrition in relation to drought tolerance in coconut has been explained on the basis of stomatal regulation (Braconnier and D'Auzac 1990; Braconnier and Bonneau 1998). Unlike in most of the crops where malate serves as a balancing ion for K^+, in coconut the absence of chloroplasts in the guard cells deprives the availability of malate (Braconnier and D 'Auzac 1985). Increase in drought tolerance of palms under dry conditions with the addition of KCl was reported in Ivory Coast (Ollagnier *et al.* 1983; Rajagopal and Naresh Kumar 2001). Chlorine is important in coconut nutrition and for resistance to water stress; the critical level of Cl was identified as 0.7% in 14th leaf (Bonneau *et al.* 1993 and 1997). Potassium nutrition also plays an important role in drought tolerance in coconut (Quencez and de Taffin 1981; Bopaiah *et al. 1996)*.

Screening for drought tolerance

The cell size and number, sub-stomatal cavity size, stomatal frequency, epicuticular wax content and thickness, leaf thickness, stomatal resistance water potential components, cell membrane stability are the essential anatomical and physiological traits for assessing moisture stress in plants (Rajagopal *et al.* 1991; Repellin *et al.* 1994; Naresh Kumar *et al.* 2000). Based on these, coconut germplasm collections comprising of Talls, Dwarfs and hybrids were screened under field conditions for drought tolerance (Rajagopal *et al.* 1990).

Genetic variation in leaflet anatomy in relation to drought tolerance

The anatomical basis for physiological efficiency for drought tolerance in coconut was delineated (Naresh Kumar *et al.* 2000). The study revealed that the leaf anatomical features which favour high photosynthetic rates are favourable for high transpiration rates as well. Thicker leaflets and thick cuticle are some of the xeromorphic characters observed in WCT and FMS. Correlations between anatomical features and physiological parameters also indicated that thick cuticle lowers the cuticular transpiration. The WCT and FMS, which are tolerant to water stress, had thick leaflets, thick cuticle on both surfaces, larger parenchyma, hypodermal and water cells compared to less tolerant ones (COD x WCT, GBGD and MYD). Drought tolerant types had also more scalariform thickening on xylem trachieds in vascular bundles and large sub-stomatal cavities. These traits are lesser in size in moderately tolerant cultivar like PHOT and WCT x COD. The values for these traits were least in susceptible types like COD x WCT, GBGD and MYD. However, the differences for these traits between moderately tolerant and susceptible cultivars were not great. Certain parameters like epidermal cell size (upper and lower) and guard cell size are related to the drought tolerance character of a cultivar. It is possible that the cumulative effects of all these traits contribute to drought tolerance (Naresh Kumar *et al.* 2000).

Ranking of cultivars for drought stress tolerance

All the aforesaid parameters showed clear differences between the groups and among the cultivars within the group. A significant negative correlation between stomatal resistance and transpiration rate was found in Talls, Dwarfs and hybrids. Ranking for drought tolerance was done based on all stress sensitive parameters (*viz.*, stomatal regulation, leaf water potential, lipid peroxidation, ECW content, polyphenol oxidase, super oxide dismutase, catalase and peroxidase) using parametric relationships (Rajagopal *et al.* 1990; Chempakam *et al.* 1993). All Dwarfs performed badly ranking ranks between 11 and 20, whereas all hybrids (except COD x WCT) and all Talls (except the SS Apricot, Andaman Ordinary and Laccadive Micro) were within rank 10. Based on anatomical features such as thicker leaflets, thick cuticle on both surfaces, larger palisade and spongy parenchyma cells, larger hypodermal cells, water cells and sub-stomatal cavity, genotypes like WCT, FMS and PHOT and WCT x COD hybrid were identified as relatively tolerant to drought stress (Naresh Kumar *et al.* 2000).

Thus, coconut cultivars with different levels of drought tolerance could be identified based on the desirable traits, which reflect on the overall water relations of palms. Presence or absence of desirable traits imparts higher degree of drought tolerance (e.g. WCT x WCT; FMST; LCT; WCT x COD, LCT x GBGD and LCT x COD) or drought susceptibility (e.g. MYD) (Rajagopal *et al.* 2000a).

Two cultivars - San Ramon and Ambakelle Special - were identified as drought tolerant in Sri Lanka (Wikremaratne 1987 and Fernando 1987). In Cote d'Ivoire, PB–121 was identified as tolerant while WAT was classified as moderately tolerant and Rennell Tall x West African Tall as the most sensitive to drought based on drought tolerance index and effect of edaphic drought on the leaf water status, gas exchange and membrane lipids (Pomier and de Taffin 1982; de Nuce de Lamothe and Benard 1985; Repellin *et al.* 1994).

Genetic variability for photosynthetic efficiency and water use efficiency of coconut under drought conditions

The photosynthetic rates (*Pn*) were reduced by water stress mainly due to increase in stomatal or mesophyll resistance, with higher reduction noticed in susceptible types than in tolerant types (Kasturi Bai *et al.* 1998). Drought tolerant hybrids such as WCT x COD, LCT x GBGD and LCT x COD exhibited higher increase in *Pn/gs* ratio as well as higher WUE than that of susceptible types during stress period.

The potential of palms for higher dry matter (DM) production is reflected on WUE. WUE can be determined based on dry matter accumulation (g DM mm water^{-1} used) as well as by gas exchange measurements (µmol CO_2 mmol^{-1} H_2O). Significant difference in WUE has been observed between the cultivars and hybrids. The hybrids WCT x COD, LCT x GBGD and LCT x COD, and cultivar WCT had higher WUE than the other cultivars and hybrids. Under mild stress conditions, the WUE improved in coconut juvenile palms (Rajagopal *et al.* 2000b).

Recently, efforts are on to find high WUE types in coconut germplasm using carbon and oxygen isotope discrimination method at CPCRI, India; Coconut Research Institute (CRI), Sri Lanka; and Essex University, United Kingdom.

Field trials: Nut yield in relation to intensity and length of drought stress

The intricate relationship between dry spell and stages of nut development right from inflorescence initiation to the nut maturity as well as annual nut yield in different agroclimatic zones have been well described in literature (Rajagopal *et al.* 1996; Rajagopal *et al.* 2000a). Physiological traits responsible for drought tolerance correlated with yield performance under stress conditions and some of the cultivars identified as drought tolerant also proved to be good yielders (Bhaskara Rao *et al.* 1991; Rajagopal *et al.* 1992). There were genotypic variations for drought index (Pomier and de Taffin 1982) in coconut. Naresh Kumar *et al.* (2003) worked out the influence of soil moisture conservation practices on source-sink relationship in coconut.

Drought tolerance mechanism in coconut

All the above-mentioned research results helped in deciphering the mechanism of drought tolerance and stability in yield of coconut under water stress conditions (see Fig. 1). To sum up, drought tolerance in coconut is the cumulative effect of several inductive morphological, anatomical, physiological and biochemical mechanisms (Rajagopal and Kasturi Bai 2002, Naresh Kumar *et al.* 2000). The genotypes possessing the above traits of drought tolerance can be used in breeding programmes. The genetics of these important traits are being looked into for developing future coconut improvement strategies.

Genetics of drought tolerance related to physiological and biochemical traits

To understand the genetics of drought responsive physiological traits in coconut (Rajagopal *et al.* 2000a), cultivars with desirable characters were selected and crossed in a 2 x 4 line x tester mating design to study their combining ability and gene action. Physiological parameters like, leaf water potential, transpiration rate, net photosynthetic rate (*Pn*) and lipid peroxidation were recorded in seedlings under non-stress, water stress and recovery conditions. Analysis of variance for combining ability revealed significant differences among parents and hybrids for all characters except transpiration rate on recovery and leaf water potential under stress. Seedling transpiration rate showed higher specific combining ability (SCA) effects than general combining ability (GCA) effects due to predominance of non-additive gene action indicating heterosis for this character. Leaf water potential showed a similar trend. The *Pn* under stress was additive with good combining ability, while the *Pn* during non-stress and recovery were governed by non-additive gene action that could be exploited for heterosis. In case of lipid peroxidation, gene action was unpredictable in non-stress with additive gene action being nil with low dominance. These indicate that the nature of gene actions governing drought sensitive traits can be exploited by selecting proper breeding strategies for drought tolerance.

Methodology for screening drought tolerance in coconut

Drought tolerant coconut palm can be selected at seedling stage in nursery and at maturity stage. Apart from these, one can use *in vitro* screening technique as well. The screening of coconut germplasm can be done using morphological, anatomical, physiological and biochemical traits (see Fig. 2). Molecular marker-assisted selection could also be used once developed. It is essential to note that one has to develop the threshold levels for development of stress in a given climatic and soil conditions.

Figure 1. Mechanism of drought tolerance in coconut

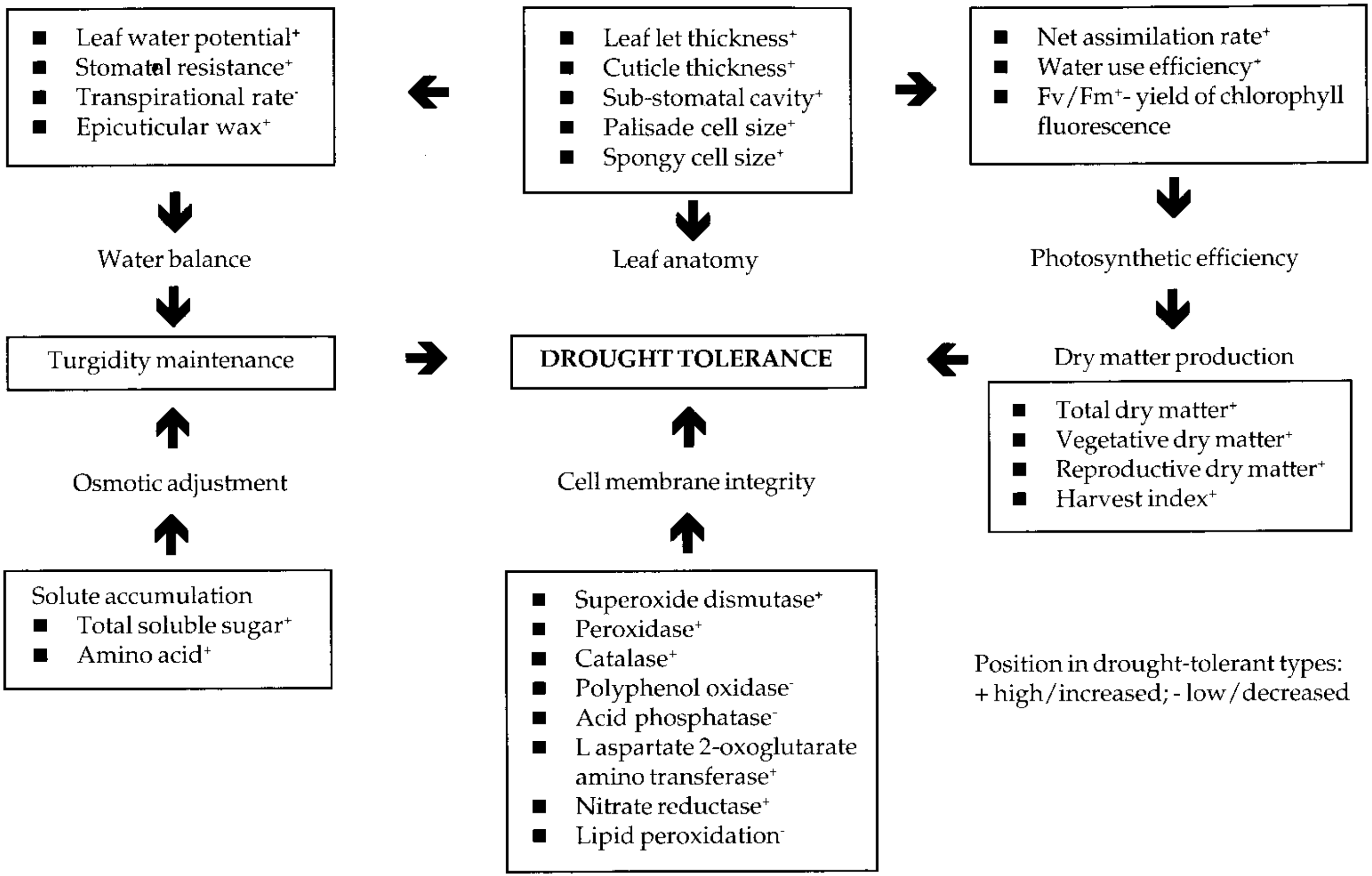
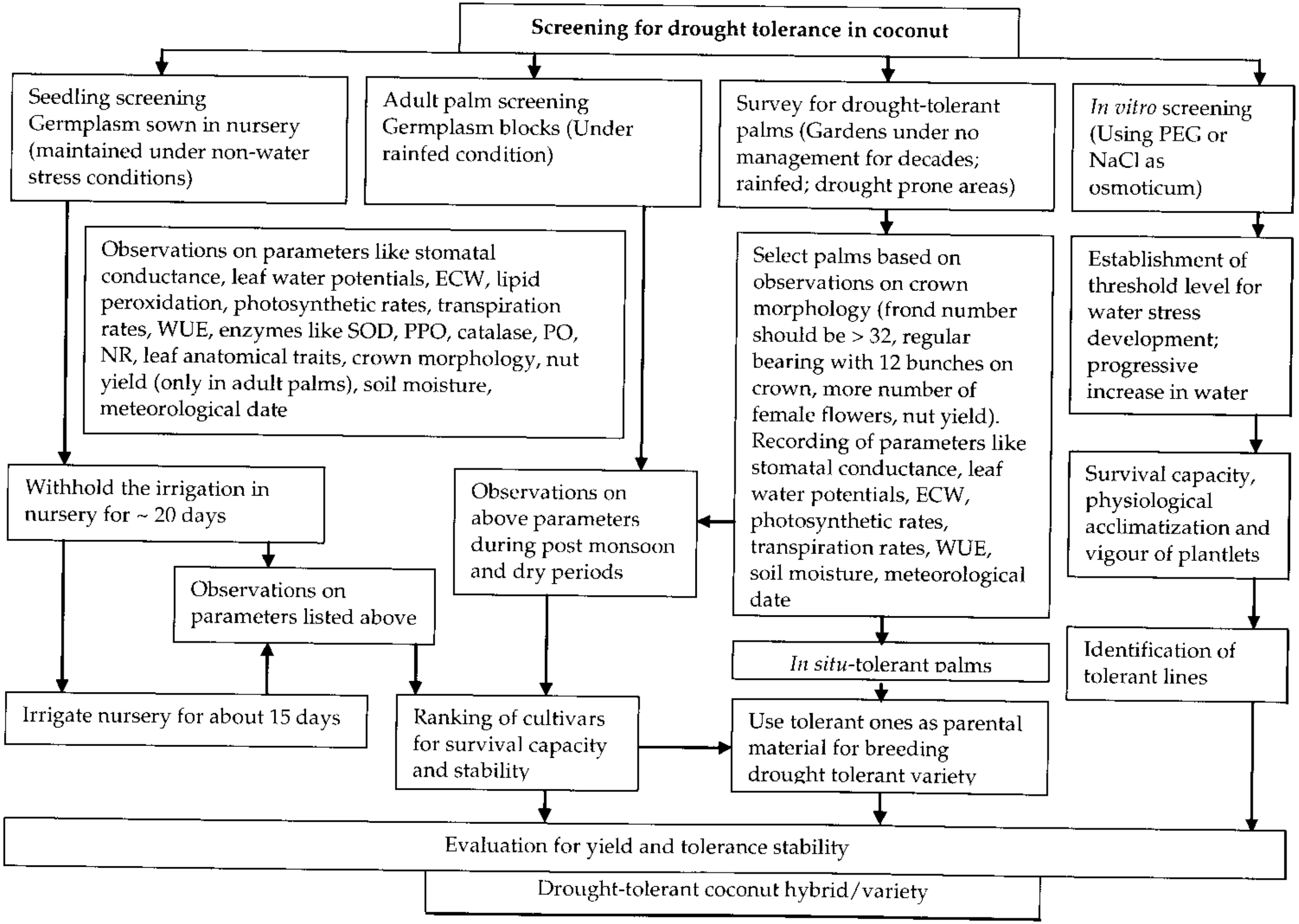


Figure 2. Schematic diagram for screening drought tolerant coconut germplasm



Identification and characterization of *in situ* tolerant palms

The plants that can withstand the natural occurrence of drought and other stresses and still produce good yields are of premium value, as they are likely to possess desirable genes. Surveys in hotspot areas were conducted to identify the palms yielding very high compared to others in their vicinity. Palms at different agroclimatic regions were identified in farmers' plots with desirable canopy shape and leaf number with good yields. The physiological WUE of these palms was also found to be high (Naresh Kumar *et al.* 2002b). This type of *in situ* tolerant plants with desirable traits should be used in breeding programmes, to reduce the time gap in breeding for drought tolerant cultivars in coconut (Naresh Kumar *et al.* 2002b).

Molecular markers for drought tolerance traits

In coconut, the development of molecular markers for drought tolerance is in its infancy. The work on stress responsive proteins is being carried out at CPCRI (Naresh Kumar 2003). Efforts are on to link the drought tolerance to molecular diversity to find putative molecular markers, which can be useful for marker-assisted selection (MAS). Although the lack of a viable regeneration technique is a bottleneck for genetic engineering of coconut palm, the molecular markers should be identified for use in large-scale rapid screening of germplasm. This will not only increase the efficiency for selection of parental material but will also reduce the gestation period for breeding improved varieties with drought tolerance (Batugal 1999). The RFLP analysis indicated that Tall and Dwarf ecotypes from Pacific and Far East Asia were different from those from India, Sri Lanka and West Africa (Lebrun *et al.* 1998, 1999). An *in vitro* screening technique was developed using NaCl as the osmoticum at different concentrations in coconut embryo culture medium (Karunaratne *et al.* 1991). It is possible to link the *in vitro* and nursery screening techniques to molecular techniques for development of molecular markers. Once the markers are established, they will be of prime importance to identify the parental material in breeding for drought tolerance. At the same time, it is essential that the stability of drought tolerance through pheno-phases should also be established.

Thus, the development of molecular markers and application of biotechnological tools for the improvement of drought tolerant coconut varieties need more emphasis and concerted efforts. The future challenge is in overcoming the bottlenecks in the use of genetic engineering for the development of drought tolerant coconut variety.

Constraints and opportunities

Drought is a major constraint for coconut productivity in the entire coconut growing area at global level. The realization of the impact of drought on coconut yield increased attention towards this problem. A methodical research approach led to understanding the drought tolerance mechanism in coconut. So far, conventional breeding strategies were applied for the development of drought tolerant varieties/hybrids. However, this takes a lot of time and so is testing for yield stability under stressful conditions. The lack of regeneration techniques handicapped the genetic engineering approach to impart drought tolerance in high yielding cultivars. Hence, it is very important that a globally-coordinated breeding programme for drought tolerance be set in place, as studies indicated that hybrids with Talls as parents can perform better under water stress conditions (Pomier and de Taffin 1982; Rajagopal *et al.* 1990). It is essential to conserve the natural desirable gene pools present in farmers' fields before they become extinct. These materials are highly valuable for crop improvement programme. Molecular markers need to be developed for rapid screening of coconut germplasm for drought tolerance at global level. Further, it is important to characterize the nature and intensity of drought in different coconut growing areas in order to develop suitable drought management strategies.

Conclusion

The results obtained so far indicate that variation exists among the Talls, Dwarfs and hybrids for drought tolerant traits. Generally, Talls and hybrids with Tall as mother palm have higher drought tolerance compared to Dwarfs and hybrids with Dwarf as mother palm. The heterosis for desirable traits can be exploited for breeding drought tolerant varieties. Further, *in situ* tolerant palms should be identified and used in breeding programme. These experiments can be extrapolated to other germplasm sources, which were not studied so far, and for making promising cross combinations. Since this requires a comprehensive study, a global research network on this topic will facilitate the development of varieties/hybrids with high drought tolerance and stable yield.

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