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Phenotypic diversity of foliar traits in coconut germplasm*

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Abstract

Coconut palm is a multipurpose crop cultivated in tropics. Diversity in this crop is rich in South Pacific Ocean and Indian Ocean Islands. Foliar traits have not been studied extensively to understand the diversity. Seven traits relevant to wind tolerance, dry matter production and taxonomic discrimination known in palms are used in the study. An attempt was made using Shannon–Weaver index with an objective to understand the level of diversity for these traits in a germplasm collection from diversity hotspot areas. Seven tall groups and four dwarf groups representing seven island territories were studied using 206 individuals. Diversity estimate was the highest in Nicobar tall group whereas it was low in tall genotypes of Fiji and Tonga. Thickness of leaf sheath fiber of weft and warp strands had shown high diversity estimates. Results obtained in this study were analyzed in relation to adaptation, geographical affinity, mating system and taxonomic forms (*typica* and *nana*) along with the importance of foliar traits in diversity of coconut.

Abbreviations: CIRAD – Centre de coopération internationale en recherche agronomique pour le développement; CGRD – International Coconut Genetic Resources Database; COGENT – International Coconut Genetic Resources Network; IPGRI – International Plant Genetic Resources Institute; FP – French Polynesia; PNG – Papua New Guinea

Introduction

Coconut palm (*Cocos nucifera* L.) is an important perennial crop in humid tropics. Tall and dwarf are the two major forms available in coconut. Tall forms are sturdy, tall in stature, pre-dominantly allogamous large fruited and late in bearing. Dwarf forms are fragile, pre-dominantly self-pollinated small fruited and early in bearing. Later group constitute only 5% of available palms. South Pacific and Indian Ocean islands are the diversity hotspots for coconut palm.

Fruit component characters are of prime importance in classifying coconut varieties (Harries 1978). Sangare et al. (1978) grouped the coconut populations into four groups based on the floral biology and pollination behaviour.

Leaf characters are comparatively stable than inflorescence and fruit traits (N'Cho et al. 1993).

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Leaf characters also have the advantage of use in seedling and juvenile palms. Leaf cross sectional area in plants has strong association with wind tolerance (Wainwright et al. 1936). Width and thickness of petiole decide this as well as give the indirect estimate of the dry weight of the entire leaf in oil palm by Corley et al. (1971) and in coconut by Friend and Corley (1994). Leaf sheath characters are known to be useful as taxonomic key in the genus *Cocothrinax* of palms (Nauman and Sanders 1991) and also known for wind tolerance in coconut (Tomlinson 1962).

Biochemical parameters like foliar polyphenols (Jay et al. 1989), foliar proteins (Cardeña et al. 1998) were also found to be useful in diversity analysis. Teulat et al. (2000) used microsatellite and AFLP markers to understand the divergence of coconut populations.

Study on diversity of foliar traits in coconut germplasm is meager. So, this effort was made to document the diversity of petiole, leaf sheath and the extent of plication (fused leaflets) in the coconut palm using 20 tall populations and four dwarf populations native to South Pacific Islands and six populations native to Nicobar Islands of Indian Ocean maintained at World Coconut Germplasm Center.

Material and methods

Rao and Koshy (1981) collected 24 accessions from six Pacific Ocean islands. These are being maintained at WCGC Port Blair, Andaman, India along with another six accessions brought from Nicobar Islands of Indian Ocean. These were effectively utilized in this study and details of the accessions used are given in Table 1. The abbreviation and synonym is as per the International Coconut Genetic Resources Database (CGRD) of IPGRI–COGENT developed by CIRAD.

Observations were recorded on 13–15 years old palms. In each palm, the oldest green leaf was cut close to the stem. Traits examined on the petiole are width of petiole, circumference and thickness. These are measured at the point of attachment of the lowest leaflets as per the methodology used by Friend and Corley (1994). Thickness was measured with the help of venier caliper.

Leaf sheath was removed from the youngest visible leaf on the crown of each palm under study. Leaf sheath was scored for presence or absence of dichotomous branching of the strands. If the dichotomous branching is present even for few strands it is taken as present. If it is not present even for a single strand it is recorded as absent. Three random fiber strands were separated from both warp and weft layers. Thickness of these warp and weft fiber strands was measured with the help of Screw Gauge. Extent of plication was studied in each leaf by counting the number of leaflets fused together.

All the tall accessions native to a country are grouped together for scoring for character states. Each dwarf accession was scored separately. All the values were summed to get total in each character state and scores were used to construct the diversity index total for the 30 accessions under study.

A total of 206 individuals representing 30 accessions (including three autogamous dwarfs and one allogamous dwarf) native to seven countries are used in the study. Sample size details are given in Table 2. Proportion (P_i) of occurrence of each character state was used in each trait (i) and the Shannon and Weaver (1949) estimates have been worked out using the formula

$$H' = -\sum_{i=1}^{n} p_i \log_2 P_i$$

where n is the total number of character states $p_i =$ proportion of individuals in the ith state of character. Calculations were performed using the example of studies in sorghum (Grenier et al. 2001). Each H' estimate is normalized by dividing $\log_2 n$.

Results

Variability of seven traits studied in 206 individuals is given in Table 2. Diversity estimates for each trait in each group are given in Table 3. Average estimate of total diversity in the study is 0.72 indicating the richness of the coconut diversity in the countries under study. Diversity estimate varied from 0.49 (circumference) to 0.97 (thickness of weft fiber of leaf sheath). Other characters recorded high diversity estimates are width of petiole (0.84), thickness of warp fiber leaf sheath (0.81) and presence or absence of dichotomous branching (0.81). Total

Table 1. Details of Tall and Dwarf accessions used in the study.

Island territory	Accession	Abbreviation used	Latitude, longitude of collection site
Talls			
Solomon Island	Solomon Island Tall	SIT	9°31′60S, 160°11′60E
	Rennel Tall	RIT	9°31′60S, 160°11′60E
Fiji	Fijian Tall Wainigata	FJT02	16°38′60S, 178°31′60E
	Fiji Niu Bulavu Tall (Taveuni Tall)	FJT01	16°51′S, 179°80′W
	Fiji Niu Drau Tall (Bulundrau Tall)	FJBT	16°51′S, 179°80′W
American Samoa	Samoan Tall	SMOT	14°20′S, 170°W
	Tutiala (Samoan Tall Alao)	SMOT02	14°20′S, 170°W
Tonga	Niu Taukave (Tonga Tall Alaki)	TONT01	21°61′S, 175°31′W
	Niu Hako (Tonga Tall Kalanga)	TONT02	21°61′S, 175°31′W
	Niu Ui (Tonga Tall Veitongo)	TONT03	21°61′S, 175°31′W
French Polynesia	Moreea Tall Pao Pao	MRT01	17°34′S, 149°52′W
	Moreea Tall Haapiti	MRT02	17°34′S, 149°52′W
	Bora Bora Tall	BBT	16°29′S, 151°45′W
	Rangiroa Tall Avatoru	RGT01	14°56′S, 147°42′W
	Rangiroa Tall Tiputa	RGT02	14°59′S, 147°37′W
	Tahiti Tall	TAT	17°46′S, 149°28′W
Papua New	New Guinea Kiriwana Tall	KRT	8°40′S, 150°55′E
Guinea	Muwa Tall	MUWT	8°45′S, 151°E
	New Guinea Kaveing Tall	KVT	2°34′S, 150°48′E
	Gazelle Peninsular Tall (Natava Tall)	GPT	2°34′S, 150°48′E
Nicobar (India)	Nicobar Tall Campbell Bay	NICT01	7°N, 93°50′E
	Nicobar Tall Katchal	NICT02	8°40′N, 93°22′E
	Nicobar Tall Kimmai	NICT03	9°11′N, 92°51′E
	Nicobar Tall Kimos	NICT04	9°11′N, 92°51′E
	Nicobar Tall Tamaloo	NICT05	9°11′N, 92°51′E
	Nicobar Tall Auck Chung	NICT06	9°11′N, 92°51′E
Dwarfs			
Fiji	Niu Leka Dwarf	NLAD	16°51′S, 179°58′W
Samoa	Niu Oma Dwarf	SYD	14°56′S, 170°37′W
Polynesia	Hari Papua Dwarf (Rangiroa Red Dwarf)	RRD	14°59′S, 147°37′W
PNG	New Guniea Orange Dwarf (Nik kore)	NGOD	2°34′S, 150°48′E

Table 2. Variability of foliar traits in WCGC coconut collection.

	Petiole dimensions (cm)			Leaf sheath fiber thickness (mm)		
	Width	Thickness	Circumference	Fused leaflets no.	Warp	Weft
Mean	6.91	3.00	17.84	8.58	1.17	0.19
Range	4.2–9.5	1.7–4.2	10.5–25.6	0–47	0.07–8.78	0.02–1.47
SD	0.99	0.41	2.55	4.68	1.05	0.16

fused leaflets and thickness of petiole recorded diversity values of 0.51 and 0.61, respectively.

Diversity estimate varied from 0.12 in Niu Oma Dwarf to 0.62 in Nicobar tall group. Other groups having high diversity estimates are Samoan tall (0.57), PNG tall (0.56) and Solomon tall (0.55). French Polynesian talls, Fiji talls and Tonga talls had diversity estimate of 0.5 or less.

Discussion

Accessions

Our findings based on foliar traits confirm the diversity richness of populations of South Pacific (N'Cho et al. 1993; Ashburner et al. 1997a, b) and Andaman and Nicobar Islands (Balakrishnan and Nair 1979).

Table 3. Shannon–Weaver index of diversity in WCGC coconut collection.

Trait	Solo. Tall	Fiji Tall	Fiji Dwarf	Am. Samoan Tall	Am. Samoan Dwarf	Tonga Tall	FP Tall	FP Dwarf	PNG Tall	PNG Dwarf	Nicobar Tall	Total
Width	0.46	0.52	0.62	0.61	0.41	0.53	0.54	0.46	0.40	0.60	0.54	0.84
Thickness	0.49	0.60	0.37	0.61	0.46	0.46	0.50	0.00	0.59	0.06	0.62	0.61
Circumference	0.49	0.40	0.30	0.54	0.00	0.00	0.09	0.36	0.34	0.34	0.23	0.49
Fused leaflets no.	0.00	0.44	0.55	0.41	0.00	0.36	0.36	0.00	0.17	0.22	0.48	0.51
Warp fiber thickness	0.96	0.38	0.47	0.30	0.00	0.18	0.46	0.50	0.85	0.55	0.88	0.81
Weft fiber thickness	0.49	0.84	0.49	0.56	0.00	0.95	0.90	0.84	1.00	0.67	0.97	0.97
Dichotomy (±)	0.97	0.00	0.00	0.93	0.00	0.00	0.66	0.88	0.55	0.99	0.65	0.81
Average	0.55	0.45	0.40	0.57	0.12	0.35	0.50	0.43	0.56	0.49	0.62	0.72
Sample size	5	23	14	20	6	15	35	10	31	11	36	206

Geographical affinity

Geographical analysis of genetic variation in pacific coconut palm populations (Ashburner et al. 1997a) showed continuous variation. The study also revealed the presence of two major groups based on geographical location, viz. northern/eastern and southern. They also found low diversity in populations of south central Pacific (Cook, Fiji and Tonga) using RAPD markers (Ashburner et al. 1997b). It is attributed to the limited source of seed material used in the past century in establishing coconut plantations in these countries.

Nearly 40% of the coconut palms in Fiji are over 50 years of age and senile (Manicot and Sivan 1991). Low diversity estimates recorded in our study on Fiji and Tonga talls support this fact. Stability of nut yield of Fiji tall over five other varieties has been noticed by Khan et al. (2002) based on the seven years yield data recorded at three different locations in India. Uniformity of such accessions could be favorably exploited in breeding programs.

Indiscriminately collected seed nuts from existing local stands were used to plant in coconut gardens of PNG without exercising selection (Ovasuru 1993). Nearly half of the plantations are nearing senility in this country. This clearly shows the need to know the history of coconut populations in a region to get an idea of the genetic diversity. Such knowledge is available and has been utilized in regions like Mexico (Zizumbo-Villareal and Arellano-Morin 1998).

Highest diversity is noticed in Nicobar tall group. Nicobar islands have large coconut stands, which are deposited by oceanic currents and mostly wild populations and regenerated by nature without intervention. Fruit data by Leach et al. (2003) clearly indicates the interference of human influence in survival of wild form.

Human population in this island is less dense and commercial exploitation is meager in the past century. Wide range of variability in coconut in these islands, viz. fruit length (10–36 cm) fruit size (micro to giant), *typica*, *nana*, *plicata spicata* and special forms unique to Andaman and Nicobar region such as the beaked fruits, lanceolate shape and horned fruits (Balakrishnan and Nair 1979).

Apart from this phenotypic diversity, coconut palms of Nicobar also show association with diverse fauna (Robber crab, many insects and termites). This region originally belongs to the ancient Gondwanaland from where fossil coconuts were recovered (Rajasthan, India by Kaul 1951; Queensland, Australia by Rigby 1995).

Botanical form and mating system

Typica (tall), *javanica* (intermediate) and *nana* (dwarf) are the major botanical forms in the coconut. Botanical and agronomic traits found to discriminate these forms (Sugimura et al. 1997). Tall and dwarf forms also known to be genetically distinct based on the superior performance of hybrids between these two forms and also seen with the analysis of unexpressed sequences of DNA by using different sets of molecular markers (RAPD – Upadhyay et al. 2002) (SSRs – Perera et al. 1999), (AFLP and SSRs – Teulat et al. 2000) and (RFLP – LeBrun et al. 1998).

Dwarfs being autogamous are found to be less diverse and different from three groups of talls based on analysis of pattern of phenotypic diversity in Mexico (Zizumbo-Villarreal and Pinero 1998). Our study also found the talls to show high degree of diversity than dwarfs.

Rangiroa Red dwarf had shown a medium diversity estimate in our investigations. Peculiar position of a similar accession Polynesian Red dwarf has also been noticed by phenol profile study by Jay et al. (1989). Heterozygosity of two out of four dwarfs has also been reported from Philippines using microsatellite loci (Rivera et al. 1999). Nik kore dwarf from Papua New Guinea (PNG) has shown high diversity among the dwarfs studied. This population has shown to be highly variable based on other morphological characters as well. Our experience also indicates the large number of off-type palms in the field not confirming to original Nik kore standard descriptors. Allogamous Niu Leka dwarf had shown the highest gene diversity among dwarf samples analyzed (Meerow et al. 2003).

Dwarf from American Samoa recorded the lowest diversity estimate. This could be ascribed to its autogamous nature coupled with the yellow color marker trait. Due to strict autogamous pollination behaviour the plant breeds true-to-type seedlings and any off-type seedlings could be identified by the absence of yellow colour in the petiole. Two recessive genes (*rrgg*) control the yellow colour of petiole (Bourdeix 1999) in coconut. Very low diversity was also seen in a similar population Vanuatu Red dwarf owing to its autogamous nature (Ashburner et al. 1997b). Our data also support the evolution of low diversity in dwarf coconut due to its autogamous behaviour.

Traits

Leaf sheath traits

Pacific and Nicobar Islands host a large population of wild forms of coconut and they undergo severe stress due to heavy winds (Marty 1986). The vascular skeleton of coconut leaf base analyzed by Tomlinson (1964) reveals a unique feature in coconut palm. It is the presence of a filling material between warp and weft, the two major fiber strands forming the leaf sheath. It is not present even in the related genus such as *Elaeis*. According to him, it could be an adaptive mechanism to heavy winds in coconut or it may be the difference in phyllotactic spiraling between oil palm and coconut. Our experience shows the correlation coefficient values of seven twin coconut palms in this farm for warp and weft fiber strands to be 0.69 and 0.80, respectively, which supports the greater proportion of heritable nature in this trait.

Structure of leaf sheath, thickness of the strands of the leaf sheath, number of leaf sheath layers, degree of tightness of strands are found to be important traits of taxonomic significance in an ornamental palm genus *Cocothrinax* (Nauman and Sanders 1991). Persistence of leaf sheath is also an important taxonomic discriminating trait in the fern *Ophioglossum vulgatum* L. The study also indicates the adaptive significance of retaining leaf bases and sheaths for 3 years in *Ophioglossum engelmannii* Prantl in aiding its survival in a comparatively dry microclimate and an alkaline soil (McAlpin 1971).

Coconut stem has a single terminal bud and follows a monopodial growth. Vascular skeleton of leaf base embraces the leaf with the stem. Warp and weft layers of this sheathing material not only serve as a barrier to the damage by insects or pathogens but also help to balance the wind movement. Terminal bud of the palm if damaged by Red weevil or *Phytophthora* pathogen it could result in mortality. Thus, survival of the palms in the stress areas depends on the strength of leaf sheath strands.

All these evidence support the high diversity seen for leaf sheath traits in our study. Further studies using conventional and molecular genetics of leaf sheath and associated traits could help in enhancing the knowledge of tolerance to biotic and abiotic stress and evolutionary and adaptive significance so as to use them in analysis of intra and inter population diversity.

Petiole dimensions

Petiole traits have played a significant role in adaptive evolution of coconut palm. Sugimura et al. (1997) also found the petiole width and petiole thickness to contribute to divergence. Pacific and Nicobar island coconut populations are subjected to heavy winds. Width and thickness of petiole are used to work out cross-sectional area and dry matter production (Friend and Corley 1994). Semicircular cross sectional area of the petiole aids the plant to tolerate wind by offering high bending resistance (Wainwright et al. 1936).

Extent of plication

There are certain mutant coconut palms possessing maximum fused leaflets even after decade of planting known as *plicata* (Sugimura et al. 1994). They are known to be late in flowering and bearing. Padmanabhan (1998) reports the regular intercostal folds giving high degree of symmetry of placations in coconut. Several structural and activity patterns of laminar meristem control the architecture of plication. A single recessive gene controls this trait in oil palm (Zeven 1964). Arunachalam et al. (2001) carried out the morphological characterization of *plicata* palms.

In the present study, only Niu Leka dwarf having rare combination of allogamous and dwarf stature has shown high diversity for this trait. Being an allele of recessive nature its occurrence is low in frequency in nature. Further, the trait is not preferred by humans for cultivation due to the association with undesirable trait of late bearing.

Boron deficiency also leads to this type of symptoms. However, *plicata* mutant palms do not respond to boron application and continue to remain with fused leaflets. Based on empirical analysis of boron uptake in normal and *plicata* palms, one may possibly find this trait as an adaptive evolution in areas of boron deficiency. Severe boron deficiency is noticed in South Pacific areas like Bareroko seed garden of Solomon Islands by Manicot and Sivan (1991).

Diversity estimates worked out in coconut germplasm collection reveal the relevance of leaf sheath traits in divergence. Importance of other adaptive traits of the leaf such as petiole width and thickness and extent of plication in divergence are also highlighted in this study. Diversity in a location is mainly decided by the history of populations. Coconut diversity in general is rich in south Pacific except south central Pacific. Diversity rich Nicobar Islands need to be explored to utilize them effectively in breeding programs. This study has practical implications in assessing the importance of accession being collected using the traits of leaf sheath and petiole. Being common to the juvenile stage, the progenies could be tested for identity using these traits. Knowledge derived from this work would serve as complementary information for developing the core collection and other genebank management activities.

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