ISSN – 0215-1162

Cord

International Journal on Coconut R & D - Vol. 40,2024

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ICC Member Countries	**Free**
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Fax No. : (62-21) 3101007
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KOH SOO PENG
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L. C. PRIYANTHIE FERNANDO
Former Director
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Lunuwila 61150, Sri Lanka
Email: priyanthiefernando@yahoo.co.uk

LALITH PERERA
Additional Director
Coconut Research Institute
Bandirippuwa Estate, Lunuwila, Sri Lanka
Email: lalithperera1234@yahoo.com

LUC BAUDOUIN
Geneticist
CIRAD - AGAP
Avenue Agropolis
34398 Montpellier Cedex 5
France
Email: luc.baudouin@cirad.fr

MELDY L. A. HOSANG
Senior Researcher and Head Plant Protection Division
National Research and Innovation Agency (BRIN)
North Sulawesi, Manado
Indonesia
Email: meldyhosang@yahoo.com

MILLICENT WALLACE
Botanist/Plant Breeder & Director
Research Coconut Industry Board
Ministry of Agriculture
18 Waterloo Road, Kingston, Jamaica
Email: millieall04@yahoo.co.uk

P. CHOWDAPPA
Former Director
ICAR-Central Plantation Crops Research Institute (CPCRI)
Kudlu. P.O, Kasaragod, Kerala 671124, India
Email: pallem22@gmail.com

PONNIAH RETHINAM
Plantation Crops Management Specialist
18, Lakshmi Nagar S. N. Palayam Coimbatore 641007
Tamil Nadu, India
Email: palms02@hotmail.com

RAMON L. RIVERA
Acting Deputy Administrator (R&D)
Philippine Coconut Authority
Philippines
Email: rlrivera_pca@yahoo.com.ph

ROLAND BOURDEIX
Diversiflora Expertise
1444 route de Mende Escalier G169 34090
Montpellier , France
Email: roland_bourdeix@yahoo.fr

ROSA S. ROLLE
Senior Enterprise Development Officer
Food and Agriculture Organization
Viale delle Terme di Caracalla
00100 Rome, Italy
Email: Rosa.Rolle@fao.org

STEIVIE KAROUW
Director
Indonesian Institute for Instrument Standardization of Palm Crops
Manado, Indonesia
Email: steivie591972@gmail.com

STEVE W. ADKINS
Professor in Plant Physiology
School of Agriculture and Food Science (SAFS)
Centre for Plant Science, Queensland Alliance for Agriculture and Food Innovation
The University of Queensland
St Lucia 4072, Brisbane, Australia
Email: s.adkins@uq.edu.au

SUCI WULANDARI
Agricultural Social Economy Scientist
Indonesian Center for Estate Crops Research & Development
Indonesian Agency for Agricultural Research & Development
Bogor, Indonesia
Email: suciwulandari@hotmail.com

S. SUDARSONO
Research Scientist
Plant Molecular Biology Laboratory
Department of Agronomy and Horticulture
Faculty of Agriculture, IPB University
Bogor 16680, Indonesia
Email: s_sudarsono@ymail.com

U. S. SARMA
Director
Indian Jute Industries' Research Association (IJIRA)
17, Taratala Road
Kolkata-700 088, India
Email: uss_2000@yahoo.com
director@ijira.org

VINCENT JOHNSON
Former COGENT Coordinator
Parc Scientifique Agropolis ll
34397 Montpellier
Cedex 5, France
Email: v.johnson@cgiar.org

V. PRAKASH FRSC
Vice President International Union
of Nutritional Sciences and President IUFoST
No 58, 5A Main Vontokoppal
Mysore 570002 India
Email: prakashvish@gmail.com

VERMEN M. VERALLO-ROWELL
Adjunct Research Professor, Institute of Herbal Medicine
and Head Skin Study Group, University of the Philippines
National Institute of Health and Founder and Program Director, VMV Skin Research Center and Clinics
Chairwoman of the Department of Dermatology
Skin and Cancer Foundation
Unit 1611, Medical Plaza Ortigas
San Miguel Avenue, San Antonio Village
Pasig City, Metro Manila, Philippines
Email: vmvrmd@gmail.com

VIJITHA VIDHANAARACHCHI
Head of Tissue Culture Division
Coconut Research Institute
Lunuwila 61150
Sri Lanka
Email: vijitharma@yahoo.com

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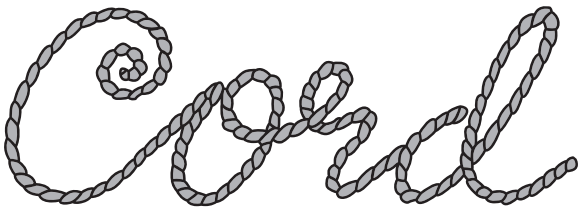

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DOI: 10.37833/cord.v40i.477
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Hengniu: Fast Bearing and High Yielding Coconut Varieties

Hengky Novarianto*, Meity A.Tulalo, Sukmawati Mawardi, and Weda Makarti Mahayu

Indonesian Palm Crops Research Institute, Indonesian Agency for Agriculture Research and Development (IAARD)

* Corresponding author. Email: hengkynovarianto83@gmail.com

Abstract

Benefits of coconut varieties that stakeholders want are early bearing, high yielding, short stems, and slow growth for height. Most local tall coconut palms in Indonesia have stem height above 20 m, making it increasingly difficult to climb to harvest fruit or tapping sap thereby making the harvesting cost high. To breed varieties of desired characters, an evaluation trial was initiated in 2014 with BYD x MTT-S4, RAD x MTT-S4, and KHINA-1 as a control. The crossing was done in 2012 and seedlings planted in January 2014 at Mapanget Experimental Garden, Indonesian Palma Crops Research Institute, North Sulawesi. The study used a Randomized Block Design (RBD) of three types of coconut hybrids, four replications with a plot size of 16 trees. Morphological observations were carried out on stem, crown and leaf characters, inflorescences and flowers, nut production, fruit components, copra, oil content, and fatty acid composition. The results of ANOVA analysis and statistical tests obtained those vegetative characters, such as stem circumference and number of leaf, generative characters namely the number of bunches, first flowering, and fruit production of these three crosses at the age of 4 years after planting, did not show a significant difference. The first initial flowering was in the coconut hybrid of RBD x MTT-S4, which is 26 months, followed by BYD x MTT-S4 in 32 months and KHINA-1 in 36 months after planting. The results of the analysis of fruit and copra production at the age of 5 years showed a significant increase between hybrid coconuts. The highest to lowest fruit production was obtained in BYD x MTT-S4 hybrid coconut, RBD x MTT-S4, KHINA-1, which were 64 nuts, 44 nuts and 26 nuts /palm respectively, or estimated copra production was 2.26 tons, 1.45 tons and 0.88 tons copra/ha. At 6 years old the harvest of fruits from the three hybrid coconuts is obtained sequentially 118 nuts, 99 nuts and 94 nuts/palm. While estimation of copra yield per hectare is found the highest in BYD x MTT-S4 hybrid coconut is 3.86 ton/ha/year and this yield differently significant compare with RBD x MTT-S4 is found 3.04 ton/ha/year, and control hybrid of KHINA-1, which is about 2.74 ton/ha/year. Based on the production potential, hence the estimated optimum production when aged over 10 years can reach more than 5 tons/ha/year. The hybrid coconut variety BYD x MTT-S4 is released in October 2019 under the name HENGNIU.

Key words: Coconut hybrid, early bearing, high yielding, short-trunked, oil content, fatty acid

Introduction

The results of various evaluation trials with hybrid coconuts conducted at Indonesian Palma Crops Research Institute (IPCRI) since the early 1980s resulted the release of four hybrids Tall x Tall hybrids viz., KB-1 (MTT-32 x MTT-32), KB 2 (MTT-32 x MTT-2), 3(MTT-32 x MTT-83), and 4 (MTT-32 x MTT-99) (Rompas et al., 1989); and five Dwarf x Tall hybrid viz., KHINA-1 (NYD x TAT), KHINA-2 (NYD x BIT), KHINA-3 (NYD x PUT), KHINA-4 (RBD x MTT), and KHINA-5 (BYD x MTT). Copra production of KHINA1, KHINA-2 and KHINA-3 hybrids is between 4-5 tons/ha /year (Novarianto et al., 1984), and for KHINA-4 and KHINA-5 is 3.5 tons/ha/year.

In 2005, the Minister of Agriculture of Indonesia released three Dwarf coconut varieties, which are high yielding fruits, and starting flowering from the age of 3 years. Compared to Tall varieties, Dwarf varieties are expected to be more homozygous because of self-pollination. Mapanget tall coconut is one of the superior coconut varieties in Indonesia (Anonymous, 1991).

Hybridization between inbred lines is expected to produce large heterosis (ref). The fourth generation selfed population of Mapanget Tall (MTT-S4) is found to be more homogeneous than the parental population MTT-S3 as seen with RAPD marker analysis (ref). The results of the hybridization between MTT-S4 and three Dwarfs are discussed in this paper.

Materials and Methods

The research activities on the Dwarf x-MTT-S4 coconut assembly have been carried out since 2012. The activity began with the selection of the parent trees of Bali Yellow Dwarf (BYD), Raja Brown Dwarf (RBD), and Tenga Tall (TAT) coconut in the Mapanget Experimental Garden, Nias Yellow Dwarf (NYD) was selected in the Paniki Experimental Garden, and coconut male parent trees in Mapanget generation selfing 4 (MTT-S4) in the Kima Atas Experimental Garden. The BYD, RBD, and NYD are used as female parents. The MTT-S4 and TAT coconut are used as male parents. The mature TAT and MTT-S4 coconut inflorescence are taken from selected male parent, then processed in the Breeding Laboratory, Indonesian Palma Crops Research Institute (IPCRI), Manado. The MTT-S4 and TAT coconut pollen, put in a plastic bottle, and stored in the freezer. Pollen processing techniques were used as per the standard manual at IPCRI (Ditjenbun, 2014). Hybridization of BYD x MTT-S4, RBD x MTT-S4, and NYD x TAT was carried out. KHINA-1 was used as the control. Hybridization was carried out in 2012 for 6 months, and continued with observing the fruit settings. In 2013 observations were made on the development of fruit setting, and harvested at the age of 11 months from pollination. Seednuts harvested were sown in nursery beds and on germination shifted on polybags. Planting was done in January 2014 at Mapanget Experimental Garden. Observation of vegetative growth of plants were recorded during 2014 to 2017 and reproductive characters and fruit production during 2017 to 2019.

The study used a Randomized Block Design (RBD). Spacing was 8.5 m x 8.5 m. The experimental design

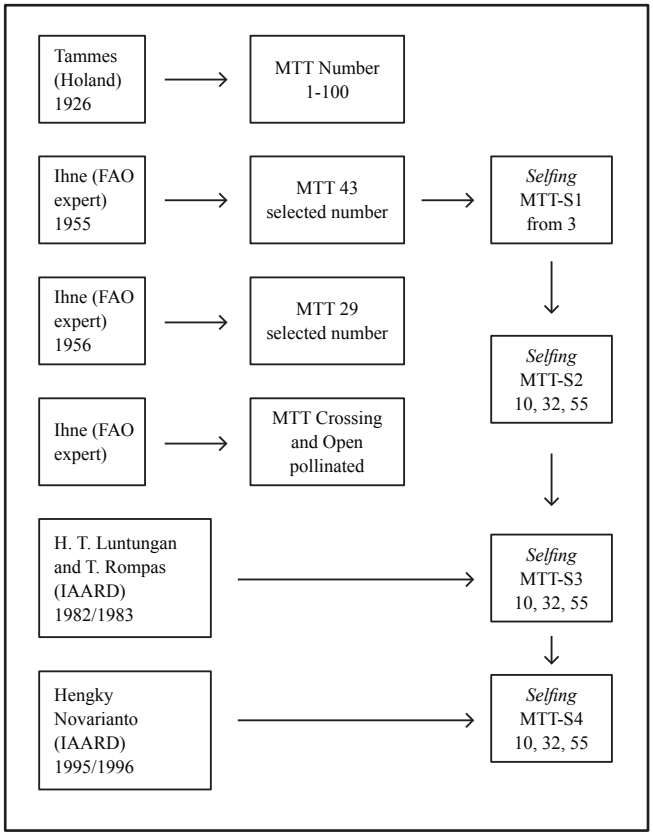

Figure 1. The origin of elders Mapanget tall coconut variety

uses four replications and each replication or plot consists of 16 palms. So, it has been planted 3 x 4 x 16 = 192 palms. Observations were made on morphological characters, such as stem character, crown and leaf, inflorescences and flowers, production, fruit components, copra, oil content, fatty acid content and composition, and resistance to Phytopthora palmivora disease.

Morphological, generative, and fruit production observations, and coconut fruit components, namely:

1. Stem: consists of a stem circumference at 20 cm, stem circumference at 1.5 m, length of stem with 11 leaf scars,
2. Leaf: crown shape, petiole color, number of leaf, rachis length, petiole length, petiole width, petiole thickness, number of leaflets, leaflets length, and leaflets width,
3. Inflorescence: number of bunches, length of peduncle, length of the central axis, thickness of peduncle, width of peduncle, number of spikelets and number of female flowers,
4. Fruit: number of fruit, fruit color, shape and size of whole fruit and shape and size of nut,
5. Fruit components: fruit weight, nut weight, weight split nut, shell weight, meat weight, and copra.

Other Supporting Data

a. Analysis of copra oil content *),
b. Analysis of coconut oil fatty acid composition and content *),
c. Analysis of macro and micronutrients in the experimental site **),
d. Analysis of macro and micronutrients in leaf number 14 hybrid coconut **),
e. Evaluation of Phytophthora palmivora disease attacks,
f. Financial Analysis of Hybrid Coconut.

Result

In the figure 1 can be seen the origin of Mapanget tall coconut by mass selection until individual selfing to get the homozygous genotype. The origin of Mapanget tall population selected by positive mass selection and get 100 best palms from population in Mapanget district, Minahasa region, North Sulawesi Province by Dr. Tammes in 1926. Dr. Ihne, who is FAO expert selected 43 number families by negative mass selection, and following by positive mass selection and got 29 number families as the best palms. Apart from that, selection has been carried out on the 3 best family numbers, namely numbers 10, 32, 55, and self-pollination has been carried out to obtain a population that is more homozygous. Self-pollination of these 3 family numbers was carried out until the 4th generation. This 4th generation population was chosen as the pollen source to be pollinated on Nias Yellow Maturity coconuts, and a HENGNIU hybrid was obtained.

Vegetative Character Growth and Development Age 1-4 years

Observation results of vegetative growth and development of hybrid coconut BYD x MTT-S4, RBD x MTT-S4, and KHINA-1, namely stem circumference and number of leaves are presented in Table 1. The ANOVA showed that characteristics of stem circumference at 1-4 years for these three hybrids coconut did not show any significative difference.

Number of Bunches and First Flowering Age 4 years

Observation of the character of the number of coconut bunches and the number of first flowering can be seen in Table 2. Observation of the number of coconut bunches and number of fruits until 4 years after planting obtained a number of bunches between 11.00-13.04 bunches/palm, and the number of fruits between 14.45-18.65 nuts /palm, but these two characters in the first year began to flower and fruiting is not yet significantly different among the hybrid coconuts.

Table 1. Vegetative character of stem circumference and number of leaf of three hybrid coconuts aged 1-4 years

No.	Hybrid coconuts	Stem circumference (cm) at aged (years)			
		1	2	3	4
1.	BYD x MTT-S4	17,62 a	51,70 a	138,03 a	151,72 a
2.	RBD x MTT-S4	16,21 a	43,22 a	131,32 a	134,12 a
3.	KHINA-1	18,55 a	53,96 a	140,55 a	157,61 a

No.	Hybrid coconuts	Number of leaf (leaf) at aged (years)			
		1	2	3	4
1.	BYD x MTT-S4	9,75 a	12,65 a	16,78 a	24,62 a
2.	RBD x MTT-S4	9,81 a	12,16 a	16,09 a	22,48 a
3.	KHINA-1	9,84 a	12,26 a	16,74 a	24,46 a

Table 2. Number of bunches and fruits of the three hybrid coconuts aged 4 years after planting

Characters/ hybrid coconuts	Parameter		
	Average	SD	CV (%)
BYD x MTT-S4	12,08 a	4,01	33,15
RBD x MTT-S4	13,04 a	2,85	21,89
KHINA-1	11,00 a	4,20	38,16
Number of fruits/palm (nuts)			
BYD x MTT-S4	17,83 a	12,67	71,07
RBD x MTT-S4	18,65 a	8,78	47,05
KHINA-1	14,45 a	10,80	74,75

Characteristics of Stem Morphology, Leaf and Inflorescence

Observations of stem morphology, leaf on the (?) coconut hybrid Bali Yellow Dwarf x Mapanget Tall-S4 (BYD x MTT-S4) are presented in Table 3. Observations at 6 years of age show the character of BYD x MTT-S4 hybrid coconut is generally spherical, or semi-spherical. The girth measurement at 20 cm above soil level is 148.33 cm and the girth measurement at 1.5 m above soil level is 84.43 cm. These results indicate that the lower stem circumference is greater than the upper stem circumference, meaning that the

Table 3. The average, standard deviation (SD), Coefficient of Variance (CV) of stem morphology, leaf and inflorescencia of BYD x MTT-S4 hybrid coconut

No.	Characters	Average	SD	CV (%)
1.	Shape of crown	*Spherical*	-	-
2.	Girth measurement at 20 cm above soil level (cm)	148.33	9.66	6.51
3.	Girth measurement at 1.5 m height (cm)	84.43	5.22	6.18
4.	Length (cm) of stem with 11 leaf scars	78.54	12.06	15.36
5.	Number of leaves	24.05	1.66	6.94
6.	Colour of petiole	Green-Yellow	-	-
7.	Petiole length (cm)	170.25	12.02	7.06
8.	Petiole thickness (cm)	3.19	0.19	5.96
9.	Petiole width (cm)	7.41	0.35	4.83
10.	Rachis length (cm)	417.30	17.32	4.15
11.	Number of leaflets	190.10	21.27	11.19
12.	Leaflet length (cm)	136.54	16.94	12.41
13.	Leaflet width (cm)	5.26	1.30	24.86
14.	Length of peduncle (cm)	61.70	5.24	8.49
15.	Thickness of peduncle (cm)	2.02	0.37	18.74
16.	Length of central axis (cm)	71.40	6.68	9.36
17.	Number of spikelets	34.45	4.78	13.88
18.	Number of spikelets with female flowers	23.05	5.80	25.19
19.	Length of first spikelet bearing female flower	45.20	6.37	14.11
20.	Number of female flowers	25.70	7.94	30.92
21.	Fruit polar circumference (cm)	55.00	2.20	4.00
22.	Shape of fruit (polar view)	*Round/Egg-shaped*	-	-
23.	Fruit equatorial circumference (cm)	50.00	3.35	6.70
24.	Shape of fruit (equatorial view)	Round	-	-
25.	Nut polar circumference (cm)	38.00	2.21	5.82
26.	Nut equatorial circumference (cm)	40.00	3.14	7.85
27.	Shape of husked nut	*Almost round*	-	-
28.	Fruit colour	*Green-Yellow*	-	-
29.	Fruit size	*Medium*	-	-

BYD x MTT-S4 hybrid coconut has a bole. Bole in coconut palms indicates including in the type of tall coconut and or type of hybrid coconut, but in general the type of tall coconut bole is larger than the bole of hybrid coconut or intermediate.

Fruit Production and Components

The results of analysis of fruit component weight and fruit and nut size of the three hybrid coconuts are presented in Table 4. The observation of fruit component data from the three hybrid coconuts showed that the biggest fruit weight was obtained in KHINA-1 hybrid coconut of 1,764 gr, followed by RBD x MTT-S4 of 1,518 gr and the lowest on BYD x MTT-S4 of 1,304 gr. The shape of the fruit can be seen from the size of the polar circumference and the equatorial circumference of almost all three for each size, which are classified as egg-shaped.

The results of observation of coconut fruit production until the age of 4 years were obtained from the three hybrid coconuts, respectively 18 nuts/palm, 19 nuts/palm and 14 nuts/palm have not shown statistically significant differences (Table 5). Likewise, if converted into copra, all three are 4.46 kg/palm, 4.74 kg/palm and 3.11 kg/palm. The estimated fruit production per hectare of these three hybrid coconuts is 2,484 nuts/ha, 2,622 nuts/ha and 1,932 nuts/ha at the age of 4 years after planting. Novarianto, et al. (2017) reported that the Lampanah tall coconut has a bunches number of 13.35 palm, the number of nuts 9.25/bunch, or an average of 138 nuts/palm/year.

Stem Height

The observation of stem height and length of stem with 11 leaf scars is shown in Table 6. The average height of hybrid coconut stems is not significantly different, where BYD x MTT-S4 hybrid coconut with 239 cm stem height, then RBD x MTT-S4 hybrid obtained 219 cm, and the comparison of 241 cm of KHINA-1. Furthermore, for the character of stem length with 11 leaf scars, it was shown that the RBD x MTT-S4 hybrid coconut was significantly different from the comparison of KHINA-1, which was on average 70 cm with 85 cm, whereas on the BYD x MTT-S4 hybrid coconut which had average length of stems 11 leaf scars is 78 cm, not significantly different from both. Shorter stems in BYD x MTT-S4 and RBD x MTT-S4 hybrids coconut show the effect of inbreeding which can cause the distance among leaf scars to be shorter to each other. Mahayu and Novarianto (2015) reported that the seedlings produced by BYD x MTT-S4 hybrid coconut were shorter than seedlings of KHINA-1.

Analysis of fat and fatty acid composition

The coconut meat samples of BYD x MTT-S4 hybrid coconut, RBD x MTT-S4 and KHINA-1 have 500 gr each, which are processed into copra with 5% moisture content. The copra yield obtained for the three hybrid coconuts was obtained at BYD x MTT-S4 of 58.08%, then hybrid RBD x MTT-S4 coconut was 55.33%, and hybrid KHINA-1 was 50.79%. Copra samples from each hybrid coconut are analyzed for oil content, fatty acid composition and fatty acid content. The results of analysis of fat, fatty acids content and fatty acid composition are presented in Table 7.

Discussion

In 2012 the MTT-S4 coconut was used as a source of pollen and was crossed with the Bali Yellow Dwarf (BYD) and Raja Brown Dwarf (RBD) coconut as a hybrid coconut testing material and compared to the control of hybrid coconut Nias Yellow Dwarf x Tenga Tall (KHINA-1). Until 2019 this MTT-S4 coconut from the three numbers, namely MTT-S4-10, MTT -S4-32 and MTT -S4-55 still survive as many as 150 palms and can be used as pollen sources. Mapanget Tall coconut (MTT) was released as one of the national superior varieties in 2014 with the Decree of the Minister of Agriculture of the Republic of Indonesia No.132/Kpts/SR.120/3/2004 (Department of Agriculture, 2004).

Table 4. The results of analysis of fruit component of BYD x MTT-S4, RBD x MTT-S4 and KHINA-1 hybrid coconuts

Characters		Hybrid coconuts		
		BYD x MTT-S4	RBD x MTT-S4	KHINA-1
Fruit weight (gr)	X	1.304	1.518	1.764
	SD	170	363	277
	CV (%)	13,10	23,90	15,69
Fruit polar circumference (cm)	X	55	57,25	60
	SD	2,20	4,23	3,36
	CV (%)	4,00	7,45	5,57
Fruit equatorial circumference (cm)	X	50	51	58
	SD	3,35	8,92	3,01
	CV (%)	6,74	17,49	5,17
Nut weight (gr)	X	991	1.175	1.359
	SD	132	298	247
	CV (%)	13,32	25,37	18,16
Nut polar circumference (cm)	X	38	41	43
	SD	2,21	3,03	1,80
	CV (%)	5,74	7,32	4,21
Nut equatorial circumference (cm)	X	40	42	45
	SD	3,14	4,00	2,55
	CV (%)	7,92	9,46	5,68
Weight of split nut (gr)	X	643	758	827
	SD	79	156	108
	CV (%)	12,33	20,57	13,06
Meat weight (gr)	X	436	532	584
	SD	45	113	73
	CV (%)	10,37	21,26	12,44
Endosperm thickness (cm)	X	1,09	1,10	1,20
	SD	0,12	0,11	0,13
	CV (%)	11,19	10,16	11,50
Copra weight (gr)	X	218	266	293
	SD	23	57	134
	CV (%)	10,36	21,49	16,32

Age 1 year after planting shows the stem circumference ranged from 16.21-18.55 cm, at the age of 2 years it increased to between 43.22-53.96 cm, then at the age of 3 years it became 131.32-140.55 cm, and after 4 years of age increases to between 134.12-157.61 cm. The addition of the largest stem circumference at the age of 2 years to 3 years old, which is increased by about 86.33-88.10 cm due to changes in the circumference of the pseudo-stem into the actual circumference of the stem. The character of the number of leaves on the coconut crown from the three hybrid coconuts based on the results of the diversity

Table 5. Average of meat weight, number of fruit and copra per palm, and estimated production per hectare on ages 4-6 years after planting

No.	Hybrid coconuts	Ages	Meat weight/ nut (gr)	Production/Palm		Production/ha*)	
				Fruit/year (nut)	Copra/year (kg)	Estimated fruit/ ha (nut)	Estimated copra/ ha (ton)
1.	BYD x MTT-S4	4 years	426,71 a	18 a	4,46	2.484	0,62
2.	RBD x MTT-S4		450,86 a	19 a	4,74	2.622	0,65
3.	KHINA-1		437,19 a	14 a	3,11	1.932	0,43
1.	BYD x MTT-S4	5 years	450,75 a	64 b	16,34 b	8.832 b	2,26 b
2.	RBD x MTT-S4		437,75 a	44 ab	10,51 ab	6.072 ab	1,45 ab
3.	KHINA-1		470,42 b	26 a	6,35 a	3.588 b	0,88 a
1.	BYD x MTT-S4	6 years	411,88 a	117,92 b	27,99 b	16.284 b	3,86 b
2.	RBD x MTT-S4		402,85 a	98,66 a	21,99 a	13.662 a	3,04 a
3.	KHINA-1		416,68 a	94,00 a	19,89 a	12.972 a	2,74 a

*) Planting distance 8.5 x 8.5 m square = 138 palms/ha.

Table 6. Average (X), standard deviation (SD) and Coefficient of variance (CV) of stem height and length of stem with 11 leaf scars on ages 5,5 years of hybrid coconut Dwarf x MTT-S4 and its control KHINA-1

No.	Hybrid coconuts	Height of stem (cm)			Length of stem with 11 leaf scars (cm)		
		X	SD	CV (%)	X	SD	CV (%)
1.	BYD x MTT-S4	239 a	28.67	12.01	78 ab	12.06	15.36
2.	RBD x MTT-S4	219 a	24.68	11.28	70 a	10.20	14.65
3.	KHINA-1	241 a	41.59	17.24	85 b	12.30	14.48

analysis did not show a significant difference in the number of leaves between BYD x MTT-S4 and GRA x DMT-S4 hybrids, against the comparison KHINA-1. The average number of leaves of the three hybrid coconuts at the age of 1-4 years in a row is between 9.81-9.84 strands; 12.16-12.65 strands; 16.09-16.8 leaf; and 22.48-24.62 leaf.

The results of the diversity coefficient analysis show the character of the number of bunches and the number of initial fruits of all hybrid coconuts is very diverse with the value of CV above 20%. The character of the number of coconut bunches was obtained between 21.89% and 38.16%. The character of the number of fruits produced was very diverse also in the three types of hybrid coconut with the value of CV between 47.05% to 74.75%. The first flowering is found in BYD x MTT-S4 hybrid coconut, i.e. 32 months after planting, RBD x MTT-S4 is earlier, i.e. 26 months, and comparison is KHINA-1, 36 months after planting. Jatmiko et al. (1990) reported that the development of a synthetic variety of coconut that flowering occurred as early as 2.5 years from field planting in two entries, BAYT x TAGT (2 palms) and WAT x TAGT (1 palm). At the age of 3.5 years, the hybrid WAT x RIT showed 50% flowering.

The length of stem with 11 leaf scars of the BYD x MTT-S4 hybrid coconut is around 78.54 cm, which indicates that this distance is quite tight between leaf scars. When compared with the male parent (Mapanget tall) which have 11 leaf scars of 113.90 cm (DMT-OP), 115.56 cm (DMT-S2), 100.45 (DMT-S3), 94.08 cm (DMT-S4) (6), and the female parent of the Bali Yellow Dwarf (BYD) coconut with 11 leaf scars as high as 43.77 cm, BYD x MTT-S4 hybrid coconut has 11 stem length leaf scars between the two parents or intermediate. The length of the stem with 11 leaf scars shows the high speed of the coconut stem. Therefore, the shorter the distance, the slower the coconut palm becomes higher. Coconut farmers want coconut trees that are short trunked so that the climber can easily harvest fruit and tapping sap to produce coconut sugar. Male parent (MTT-32 S4) which are the result of several generations of selfing show that the stem lengths of 11 leaf scars are shorter than those of Open Pollinated (OP), Selfing generation 2 (S2) and Selfing generation 3 (S3) of MTT-32 populations due to inbreeding depression (Pandin, 2010). The results of the analysis of the diversity of characters between trees show that the shape of the crown and characteristics of BYD x MTT-S4 hybrid coconut stems are quite uniform, where the diversity coefficient of variance (CV) of all characters are below 20%, between 6.18% to 14.73%. The BYD x MTT-S4 hybrid coconut has an average number of leaf petioles

Table 7. Fat content, composition and fatty acids content of BYD x MTT-S4, RBD x MTT-S4 and KHINA-1 hybrid coconuts

Parameter	Unit	BYD x MTT S-4	RBD x MTT-S4	KHINA-1	Analysis Method
Total fat	%	61.56	58.36	60.31	18-8-5/MU/SMM-SIG, Weilbul
Fatty acid composition					
Saturated fat	%	**91.89**	**91.74**	**89.96**	18-6-1/MU/SMM-SIG, GC
Butyrate (C4)	%	0.00	0.00	0.00	
Caproate (C6)	%	0.49	0.50	0.42	
Caprylate (C8)	%	6.39	5.69	5.19	
Caprate (C10)	%	5.23	4.71	4.26	
Undecanoate (C11)	%	0.01	0.02	0.02	
Laurate (C12)	%	**46.46**	**45.53**	**42.80**	
Tridecanoate (C13)	%	0.03	0.03	0.03	
Myristate (C14:0)	%	19.86	20.00	21.27	
Pentadecanoate (C15:0)	%	0.01	0.02	0.02	
Palmitate (C16:0)	%	10.35	10.66	11.82	
Heptadecanoate (C17:0)	%	0.01	0.02	0.02	
Stearate (C18:0)	%	2.93	4.37	3.96	
Arachidate (C20:0)	%	0.09	0.12	0.10	
Behenat (C22:0)	%	0.01	0.02	0.02	
Lignosefiber (C24:0)	%	0.02	0.05	0.03	
Unsaturated fat	%	8.10	8.25	10.02	18-6-1/MU/SMM-SIG, GC
Palmitoleate (16:1)	%	0.02	0.02	0.01	
Oleate (C18:1) (Omega 9)	%	6.76	6.88	8.42	
Linoleate (C18:2) (Omega 6)	%	1.29	1.30	1.56	
Linolenic acid (C18:3) (Omega 3)	%	0.00	0.02	0.01	
Eicosenoate (C20:1)	%	0.03	0.03	0.02	

of 24.05 strands with yellowish green leaf petiole color (Table 3). The petiole length is 170.25 cm, with petiole thickness and width of 3.19 cm and 7.41 cm respectively. The observation of rachis length was obtained at 417.30 cm, with the number of leaflets 190.10 leaflets. Furthermore, the character of the leaflet length is 136.54 cm, and the leaflet width is 5.26 cm. The results of the coefficient of variance analysis show that all leaf petiole characters have a fairly small diversity where the CV is below 20%, except for the leaflet width character with CV values of 24.86%.

Characteristics of inflorescences showed that the length peduncle of BYD x MTT-S4 hybrid coconut was 61.70 cm, with thickness of peduncle 2.02 cm, and length of central axis is about 71.40 cm. So that from the base of the peduncle to the end of the central axis has a length of about 133.10 cm. Spikelet is a part of a coconut bunch that is attached to male flowers, female flowers. The results of the observation showed that the average number of BYD x MTT-S4 hybrid coconut was 34.45 spikelets. Among them are the number of spikelets with female flowers of 23.05 pieces, with a spikelet length of 45.20 cm, and the number of female flowers in one fruit bunch is 25.70. Diversity analysis shows that generally the flower bunch character is quite uniform, except for the number of spikelet characters with female flowers and the number of female flowers that have CV is 25.19% and 30.92%, meaning that the diversity of these characters is quite large. Observation of BYD x MTT-S4 hybrid coconut was carried out on fruit and nut circumference of polar and equatorial. Fruit polar circumference is 55.00 cm, and the fruit equatorial circumference is 50.00 cm. Then for the nut polar circumference obtained 38.00 cm and nut

equatorial circumference is 40 cm. Comparison of polar and equatorial lengths shows that BYD x MTT-S4 hybrid coconut fruit is round to egg-shaped, while the nut shape is almost round. Fruit colour is yellowish green, and the size of the fruit are classified as medium. The nut weight is KHINA-1 the highest 1,359 gr and followed by RBD x MTT-S4 of 1,175 gr and the lowest on BYD x MTT-S4 of 991 gr. For the polar circumference of the nuts and equatorial circumference, the third hybrid is balanced in size, so it can be almost round. The thickness of the endosperm of the three hybrid coconuts is almost the same, which is around 1.09-1.20 cm. The most important component in coconut fruit is the meat weight.

The results of observations for the first fruit harvest obtained the highest meat weight on KHINA-1 hybrid coconut of 523 gr/nut, followed by RBD x MTT-S4 and BYD x MTT-S4, each weighing 463 gr /nut and 451 gr / nut. These three hybrid coconuts have a weight of meat above 400 gr/nut, already classified as one of the criteria of a good coconut. After being processed into copra, it was obtained in BYD x MTT-S4 hybrid coconut, RBD x MTT-S4, and KHINA-1, respectively copra weight was 262 gr/nut, 256 gr/nut and 266 gr/nut. Based on reports that in MAWA and MATAG hybrid coconut it was reported that it copra weighed 210 gr/nut and 250 gr/nut (UPB, 2015), while KHINA-1, KHINA-2, KHINA-3, KHINA-4 and KHINA-5 were consecutive also 253 gr /nut, 296 gr/nut, 254 gr/nut, 250 gr/nut and 245 gr/nut (Kadere et al., 2009). An evaluation trial conducted over 28 years on coconut hybrid combinations has resulted in identification of a superior, high yielding Dwarf x Tall hybrid, named as 'Kalpa Samrudhi' involving IND 058S as female parent and IND 069S as male parent. The results revealed that the hybrid is better performing over other hybrids and local control with higher fruit yield (117 fruits palm-1 year-1), high copra out turn (25.72 kg palm-1 year-1 or 4.5 t ha-1 year-1 copra) and estimated oil recovery of 3.04 tons ha-1 under rainfed conditions of Kerala (Kindangen et al., 1989).

The component weight of fruit meat, fruit production and copra per palm and estimated production per hectare at age 4, 5 and 6 years are presented in Table 5. Data in Table 5 shows that fruit production from BYD x MTT-S4 and RBD x MTT-S4 has fruit production that is consistently always higher than the control, namely KHINA-1. It can also be seen that the weight of fruit meat, fruit production and copra are the third hybrid coconut at the age of 4 years after planting, or the first harvest. The results of observing the weight of fruit components, especially the weight of fruit meat, showed that the three hybrid coconuts were equally heavy, namely hybrid BYD x MTT-S4, RBD x MTT-S4 and KHINA-1 comparison (Nias Yellow Dwarf x Tenga Tall) were 426.71 gr/nut, 450.86 gr/nut and 437.19 gr/nut.

The data observations of the components of the first year of production at the age of 5 years were analyzed for diversity and the real difference test using the Honest Significant Difference Test (HSD test), showed a significant difference in production. The average weight of coconut meat was highest in KHINA-1 hybrid coconut weighing 470.42 gr/nut, and this weight was significantly different from the weight of meat weight in BYD x MTT-S4 hybrid coconut and RBD x MTT-S4, respectively each 450.75 gr and 437, 75 gr/nut. Furthermore, the character of fruit production turned out to be the highest in BYD x MTT-S4 hybrids 64 nuts/palm, and the number of fruits was significantly different from the comparison of KHINA-1 hybrid coconut with an average yield of 26 nuts/palm for the first-year harvest when age of 5 years. Production of RBD x MTT-S4 hybrid coconut fruit, which is 44 nuts/palm, was not significantly different from BYD x MTT-S4 hybrid coconut and its control was KHINA-1. The results of the analysis of copra production from the three hybrid coconuts showed that BYD x MTT-S4 hybrid coconut obtained 16.34 kg/palm which was significantly different from the KHINA-1 comparison, which was around 6.35 kg/palm, while RBD x MTT-S4 hybrid coconut produce 10.51 kg copra/palm, which the statistical test results are not significantly different from BYD x MTT-S4 and KHINA-1 hybrid coconut. Estimates of copra production per hectare with spacing in this test 8.5 mx 8.5 m, or 138 trees per hectare obtained the highest copra production in BYD x MTT-S4 hybrid coconut as much as 2.26 tons/ha/year, followed by hybrid coconut RBD x MTT-S4 is 1.45 tons/ha/year, and the lowest is in KHINA-1 hybrid coconut as a comparison, which is 0.88 tons/ha/year. The production of RBD x MTT-S4 hybrid coconut copra is significantly different from KHINA-1 at the harvesting age of 5 years after planting.

Observation of coconut meat weight of three BYD x MTT-S4 hybrid coconuts, RBD x MTT-S4, and KHINA-1 at 6 years of age from planting obtained data of 411.88 gr/nut, 402.8 gr/nut and 416.68 gr/nut, respectively equally heavy and not significantly different from each other. Coconut fruit production until the age of 6 years was significantly different based on ANOVA and the HSD test, the highest was shown by BYD x MTT-S4 hybrid coconut as much as 117.92 nuts/palm and significantly different from hybrid coconut RBD x MTT-S4, and KHINA-1, each obtained 98.66 nuts/palm

and 94 nuts/palm. The results of copra analysis were found to be significantly different, namely in the hybrid BYD x MTT-S4 coconut as much as 27.99 kg/palm which was significantly different from hybrid coconut RBD x MTT-S4, and KHINA-1, which were 21.99 kg/palm, respectively and 19.89 kg/palm. Mahayu & Novarianto (2014) reported that the results of evaluations carried out on 10 coconut varieties at the United Plantation Berhad germplasm site, Malaysia, reported the number of fruits per bunch and per tree varied, and the highest in varieties in Tagnanan Tall from Philippines and West African Tall from Cote d'Ivoire.

Estimated copra production per hectare obtained the highest copra production in BYD x MTT-S4 hybrid coconut as much as 3.86 tons/ha/year, which was significantly different from RBD x MTT-S4 hybrid coconut as much as 3.04 tons/ha/year, and with KHINA-1 as a comparison, which is 2.74 tons/ha/year. Based on the results of previous hybrid coconut observations, namely KHINA (Mahayu & Novarianto, 2015; Mangindaan, 1987), increasing fruit and copra production will continue to increase until hybrid coconut is over 8-10 years after planting. KHINA-1 hybrid coconut is reported to produce copra 5 tons/ha at the age of 10 years (Anonymous, 2009; Dyanti et al., 2002). So based on the results of the previous hybrid coconut at the age of 10 years, BYD x MTT-S4 hybrid coconuts will be able to produce copra more than 5 tons/ha/year at the same age. The results of this study at the seedling level turned out to be in line with when the plants in the field until the age of 6 years after planting that the BYD x MTT-S4 and RBD x MTT-S4 hybrids were shorter in stem than KHINA-1. The results of the diversity analysis showed that the three hybrid coconuts were quite uniform in the stem height and stem length 11 leaf scars between palms in the same hybrid coconut, where the value of the Coefficient of Variance (CV) was below 20%. For stem height characters, it can be seen that BYD x MTT-S4 hybrid coconut obtained CV value 12.01%, RBD x MTT-S4 hybrid coconut with CV value of 11.28%, and its comparison (KHINA-1) with CV of 17.24%. The smaller CV values in the two hybrid coconuts compared to the comparison showed that the homogeneity level of male DMT-S4 parents after selfing up to the fourth generation was higher, so that hybrid coconuts were produced that were more uniform on the stem height character.

The results of the analysis of fat content of the three hybrid coconuts were highest in BYD x MTT-S4 hybrid coconut at 61.56%, then KHINA-1 comparison of 60.31% and RBD x MTT-S4 hybrid coconut at 58.36%. In general, the fat content of copra from coconut is around 58-65%, such as coconut of Mapanget tall 62.95%, Bali tall 65.52%, KHINA-1 60.78%, KHINA-2 60.61%, KHINA-3 62.46%, KHINA-4 60.00%, and KHINA-5 60.08% (Ditjenbun, 2014). Coconut oil consists of saturated fatty acids and unsaturated fatty acids. The results of the analysis showed that saturated fatty acids from the three BYD x MTT-S4 hybrid coconuts, RBD x MTT-S4 and KHINA-1 were 91.89%, 91.74% and 89.96%, and the remaining around 8-10% were unsaturated fatty acids. The composition of saturated fatty acids was detected as many as 14 kinds of fatty acids, ranging from Caproid acid (C6) to Licnoceric acid (C24). The highest saturated fatty acid levels were Lauric acid (C12), Miristic acid (C14), Caprylic acid (C8) and Capric acid (C10), which in BYD x MTT-S4 hybrid coconuts were 46.46%, respectively 19.86%, 6.39% and 5.23%. Total unsaturated fatty acids are 8.10%-10.02% in the three hybrid coconuts, consisting of five kinds of fatty acids, namely Palmitic acid (16:1), Oleat (18:1) or Omega 9 Acid, Linoleic (18:2) or Omega 6 Acid, Linolenic (18:3) or Omega 3 acid, and Eicosenoic acid (20:1). Among the five unsaturated fatty acids, the highest fat content is Oleic acid (Omega 9) as much as 6.76% in BYD x MTT-S4 hybrid coconut, then 6.88% in RBD x MTT-S4 and KHINA-1 hybrid coconut 8.42%. At this time coconut oil and various coconut products are consumed by more than 1 billion people and are a basic component of the best cuisine in the world. Coconut oil is one of the healthiest oils in the world. Although coconut oil is dominated by saturated fatty acids, most of it is Medium Chain Fatty Acid (C4-C12) or MCT oil (Medium Chain Triglyceride) as an energy source that is directly absorbed by the body without going through the process in the liver. The total content of medium chain saturated fatty acids in the three hybrid coconuts was obtained for BYD x MTT-S4 by 58.58%, then in RBD x MTT-S4 of 56.45%, and hybrid KHINA-1 as a comparison obtained 52.69%. The most important fatty acids of medium chain fatty acids are lauric acid (C12), and in the three hybrid coconuts obtained 46.46% respectively in BYD x MTT-S4, then 45.53 in RBD x MTT-S4 and comparison KHINA-1 hybrid coconut is 42.80%. One of the popular and expensive coconut products is Virgin Coconut Oil (VCO), and lauric acid is the important fatty acid of VCO.

The Hengniu coconut hybrid was released as a new coconut hybrid in October 2019 by Indonesian Republic Department of Agriculture. This coconut hybrid will be used as one plant materials for coconut development and replanting in Indonesia. References remaining around 8-10% were unsaturated fatty acids. The

composition of saturated fatty acids was detected as many as 14 kinds of fatty acids, ranging from Caproid acid (C6) to Licnoceric acid C24). The highest saturated fatty acid levels were Lauric acid (C12), Myristic acid (C14), Caprylic acid (C8) and Capric acid (C10), which in BYD x MTT-S4 hybrid coconuts were 46.46%, respectively 19.86%, 6.39% and 5.23%.

Conclusion

The Hengniu (BYD x MTT-S4) hybrid coconut begins to bear fruit at the age of 3 years, and at the age of 6 years has produced fruit 118 nuts/palm, and copra 3.86 tons /ha. The length of stem with 11 leaf scars is 78 cm. The oil content of copra 61.56%, medium chain saturated fatty acid (C6-C12) 58.58%, and lauric acid content (C12) 46.46%. The Hengniu coconut hybrid was released as a new coconut hybrid in October 2019 by Indonesian Republic Department of Agriculture.

Acknowledgements

Thank you to IPCRI, ICERD and IAARD for supporting the budget for this coconut research. Thanks to Mrs. Lydia Samau for processing pollen, Mr. Anugerah Mandiangan, Mr. Nicodemus Katuuk and Mr. Merdi Mumek as an emasculator and pollinator, Mr. Leman L. Raranta as Manager of Mapanget Experimental Garden, Ms. Isti Sambenusa, Mr. Rival Saka, Mr. Tonny Surya, Mrs. Poppy Mangadil and Mrs. Suryani Lahea, whose are helping to gathered the coconut data in the field, and fruit component analysis, and Mr. Roiyan Muhammad for the GPS.

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DOI: 10.37833/cord.v40i.451
Coconut Research & Development, 2024, 40, 11-19

Development of Coconut Palm Wood Seasoning Schedules

Gayathri Mukundan, E. V. Anoop, Anish Mavila Chathoth, and Comath Shibu*

Kerala Agricultural University, Department of Forest Products & Utilization, College of Forestry, Thrissur, Kerala, India pin-680656

* Corresponding author. Email: cshibu999@gmail.com

Abstract

Coconut palm is a versatile palm in the tropical and subtropical regions. This study attempts to standardize moisture content-based kiln seasoning schedules for high-density and medium-density coconut palm wood and also understand the relationship between Pilodyn Penetration Depth (PPD) and basic density for three density classes (high, medium, and low). A quick drying test was conducted to study the degree and type of drying defects, namely surface cracking, end splitting, honeycombing, and deformation. Defects were graded according to the Terasawa (1965) scale. The baseline parameters, such as initial dry-bulb temperature, final dry-bulb temperature, and the wet-bulb depression for high and medium-density coconut palm wood, were chosen by considering the major seasoning defects. The samples were subjected to different seasoning schedule treatments in a convection kiln to determine the best treatment based on the grading of defects. The optimal kiln drying schedule for 25 mm thickness, high-density coconut palm wood was: initial dry-bulb temperature (DBT) 45°C (relative humidity 87%), wet-bulb depression (WBD) 2°C, and final dry-bulb temperature 80°C. For medium-density wood, the schedule was: initial DBT 50°C (relative humidity 88%), WBD 2°C, and final DBT 80°C. The ideal drying period was 11 days for high-density coconut palm wood and 12 days for medium-density coconut palm wood. The schedule developed has good potential for industrial application in seasoning coconut palm wood with reduced defects in coconut-growing regions of the world.

Key words: Coconut palm wood, seasoning schedule, kiln drying, Terasawa scale

Introduction

Asia-Pacific region has the lowest per capita forest cover (0.18 ha), which is just one-third of the world's per capita forest cover (0.64 ha) (FAO, 2019). Considering the growing population, per capita forest cover is declining in most countries, including India. According to ITTO (2010), East Asia (mainly China) and South Asia (mainly India) will rely heavily on imports, thereby creating intense pressure on forest-deficit countries. The global trade in tropical primary wood products is concentrated within the Asia-Pacific region. Tropical sawn-wood and veneer log exports from Asia-Pacific producers account for about three-quarters of global exports (ITTO, 2017). According to Pryor (2019), the US hardwood exports to India with sawn hardwood rose to 72%, and veneers increased by 4%. In 2019, China's hardwood log imports fell to 15% (15.31 million m3; 25% of the total national log imports) with a strong preference for teak (ITTO, 2020). Alternate sources of timber include legal sources from the northern and western hemispheres, predominantly of temperate species (teak etc.) and illegal sources (from tropical countries). The supply of plantation-grown species like Indian rubber wood (*Hevea brasiliensis*) is declining due to the steep and

unstinted fall in the price of its latex. Apart from that, Acacias and Eucalypts are posing serious ecological and social concerns. These aspects imply an insufficient raw material base for the timber industry in the future. The prospects of proper utilization of lesser-known timber species gains importance in this context (Basri et al., 2009). Potentially valuable yet underutilized hardwood substitutes such as palm 'wood' from coconut palm stems provide a viable and durable industrial raw material.

India has a vast coastline of about 7,517 km, both on the Western and Eastern coasts combined, and the state of Kerala, which has the largest planted area alone, has a 580 km coastline where large numbers of tall senile palms are present. India stands third in terms of the total area of coconut palms (2.14 million hectares), which constitute roughly 20 per cent of the total planted area. However, a large number of these palms are old, senile, and diseased (CDB, 2016). The large number of old and senile palms in Kerala and the neighboring states of Tamil Nadu necessitates large-scale felling of such tall palms and replanting with high-yielding varieties. This will increase the supply of raw materials, which are equally durable as conventional species for construction and furniture industries, albeit at a lower price.

Proper utilization of any particular wood species must be based on basic and processing properties. Drying properties are the most important processing properties (Effah, 2014). An appropriate seasoning process will be the main key to efficient utilization to ensure good quality for wood products (Hoadley, 2000). For most timber products, pre-seasoning is essential. It reduces not only the presence of water in the wood but also reduces the danger of movement of water once timber is in use. The art of successful seasoning lies mainly in maintaining a balance between the evaporation of water from the surface of the timber and the movement of water from the interior of the wood to the surface (Desch and Dinwoodie, 1981).

Coconut palm wood has an initial moisture content ranging from 60% in high-density wood (above 600 kg/m³) to as high as 230% in low-density wood (below 400 kg/m³) (Killmann, 1983). Much emphasis is placed on producing seasoned timber as quickly and economically as possible within the quality limits of specified standards. This study analyzed the green moisture content, basic density, shrinkage, and drying tests to determine drying rates and associated defects of coconut palm wood. This study aims to develop a kiln seasoning schedule for coconut palm wood based on a quick drying method for high-density and medium-density (basic density 400-600 kg/m³) coconut palm wood utilization. Low-density wood was excluded from the seasoning schedule development as it is unsuitable for making load-bearing structures.

Materials and Methods

The study was conducted in the Forest Products and Utilization laboratory, College of Forestry, KAU, Vellanikkara. Physical properties (moisture content, basic density, and shrinkage) and drying behavior of coconut palm wood were investigated through standard procedures.

Conversion of samples

Mature West Coast Tall (WCT) coconut palm trees (*Cocos nucifera*) exceeding 40 years of age and 11 m in height were selected for sample collection. The trees were collected from Thrissur district, Kerala, India (10.5276° N, 76.2144° E). Samples were then prepared according to the prescribed dimensions outlined in Indian Standard IS: 1708 (1986). For moisture content and basic density analysis, samples with dimensions of 20 mm × 20 mm × 25 mm were prepared following IS: 1708 (1986) specifications. Volumetric shrinkage analysis employed samples measuring 20 mm × 20 mm × 60 mm, as per the same standard. Samples of size 20 mm × 100 mm × 200 mm (thickness, width and length) were used for the quick drying test to understand the drying behavior.

Physical properties

1. Basic density

Thirty samples of size 20 mm × 20 mm × 25 mm were oven-dried at 103 ± 2°C to constant weight, and their oven-dried weight was calculated using a precision electronic balance (Shimadzu AUY 220). Basic density was calculated using the formula.

$$\text{Basic Density} = \frac{\text{Oven Dry Weight}}{\text{Green Volume}}$$

1.1. Indirect estimation of Basic density

Pilodyn Penetration Depth (PPD) in mm was estimated using a Non-Destructive Tool (NDT) Pilodyn 6 J (Fujiteck) for 30 samples from each of the three density classes (inner core, semi-dermal and outer dermal wood) and regression analysis was carried out to understand the relationship between PPD and basic density of coconut Palm wood. The

indirect estimation can also provide a rapid estimate of wood density for grading once seasoning schedules are developed.

2. Moisture content

Ten samples of each high, medium and low-density wood type (with dimensions of 20 mm × 20 mm × 25 mm) were used to determine their moisture content. The initial weight (Wi) of each sample was measured using an electronic balance (Shimadzu AUY 220) with a precision of 0.001 g. The samples were then oven-dried at 103 ± 2°C until a constant weight (Wod) was achieved. Moisture content (MC) on a dry basis was subsequently calculated using the following formula:

$$\text{Moisture Content} = \left[\frac{(W_i - W_{od})}{W_{od}}\right] \times 100$$

Where Wi is the initial weight of the specimen (in g), and Wod is the oven-dry weight of the same specimen.

3. Volumetric shrinkage

Ten samples of each type (high, medium, and low-density wood) with dimensions of 20 mm × 20 mm × 60 mm were used to determine the volumetric shrinkage. The test followed the procedure prescribed in Indian Standard IS 1708 (part 3) 1986. One-way analysis of variance (ANOVA) was used to determine the average volumetric shrinkage differences across the density classes. The volumetric shrinkage was calculated by using the following formula:

$$\text{Volumetric shrinkage} = \left[\frac{(V_i - V_{od})}{V_{od}}\right] \times 100$$

Where Vi is the initial volume of the specimen in green condition (in cc), Vod is the oven-dry volume of the same specimen.

Quick drying test

Ten samples of size 20 mm × 100 mm × 200 mm for both high and medium-density wood were placed edgewise in an oven at 103°C ± 2°C until constant weight was obtained. Each specimen was taken from the oven every hour for the first 8 h for weight measurement and to evaluate initial drying defects (end and surface checking). The same procedure was repeated at 24th and 30th h on the second day and 48th h (third day) to determine the weight and defects. The measurements and observations were repeated until the samples achieved constant weight. The drying defects of the samples were compared with the criteria set by Terazawa (1965). The specimens were given scores based on the classification of drying defects. Subsequently, control parameters such as the initial dry-bulb temperature, initial wet-bulb depression (difference between dry-bulb temperature and wet-bulb temperature) and final dry-bulb temperature were determined.

Table 1. Classification of defects based on Terazawa (1965) and modified by Jankowsky (1992) and method for Classification of degree of deformation on the section

	Checks		Deformation
Level of defects	**End checks (mm)**	**Surface check (mm)**	**A-B (mm)**
1.	No checks	No checks	0 - 0.3
2.	Small checks L < 10, W< 0.8	Small checks L<50, W<0.5	0.3 - 0.5
3.	Small checks L >10, W< 0.8	Small to medium checks L < 100, W > 5, W < 1, W > 1	0.5 - 0.8
4.	Medium check L >10, W< 0.8	Small to medium checks L < 100, W > 5, W < 1, W > 1	0.5 - 0.8
5.	Medium to large checks L > 10, W > 0.8, W < 1.5	Large Checks L > 150, W > 1.5	1.2 - 1.8
6.	Large checks L > 10, W< 1.5	Large Checks L > 150, W > 1.5	1.8 - 2.5
7.	Large checks L > 10, W< 1.5	Large Checks L > 150, W > 1.5	2.5 - 3.5
8.	Large checks L > 10, W< 1.5	Large Checks L > 150, W > 1.5	Over 3.5

L= Check length, W = Check width, mm=Millimeter

1. Evaluation of drying defects

A scale of 1 to 8 was used to evaluate initial checks and deformation (Table 1), while a scale of 1 to 6 was used to evaluate honeycombing (Table 2). The condition

of maximum checks was compared to the checking criteria established by Terazawa (1965), and the samples were subsequently given a corresponding score based on the classification. In saccordance with the methodology established by Terazawa (1965) and subsequently employed by Brandão & Jankowsky (1992), Basri et al. (2005), Tan et al. (2010), Ofori & Brentuo (2010), Effah (2014), and Kumar et al. (2018), each wood piece was assigned a defect score based on the severity and prevalence of defects.

Table 2. Classification of degree of honeycomb (Internal checks)

Class	**1 (mm)**	**2 (mm)**	**3 (mm)**
Degree of internal check	No check	Wide or Narrow checks	2-3 wide checks; 4-5 narrow check; 1 wide and 3 narrows
Class	**4 (mm)**	**5 (mm)**	**6 (mm)**
Degree of internal check	4-5 wide; 9 narrow; 1 wide and 4-6 narrow	6-8 wide; 15 narrow; 4 wide and 6-8 narrow	15-17 wide or continuous checks

2. Evaluation of initial check

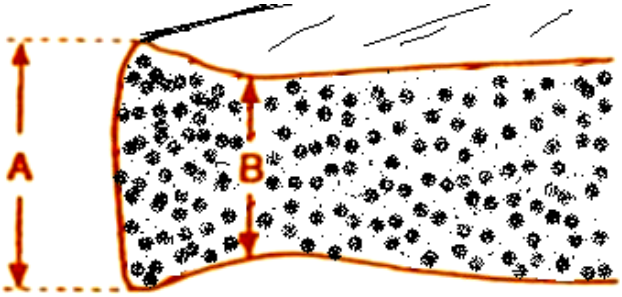
The weight and drying defects of each test sample were measured at one-hour intervals for an initial period of 8 h of drying in order to evaluate defects that evolved during the early stages of drying. The same procedure was repeated after the 24th, 30th and 48th hs of drying to determine the weight and defects. The measurements and observations were repeated until the samples achieved constant weight. Finally, the degree of initial checks was assessed on the basis of Terazawa (1965) criteria modified by Brandão & Jankowsky (1992).

3. Evaluation of honeycombs

Once the test samples attained constant weight, the samples were cross-cut in the middle part to measure the degree of honeycombing. The size and number of honeycombs on the newly exposed surfaces were recorded based on the classification of the degree of honeycombing (Table 2). Honeycombing is a specific type of cracking or splitting that occurs during the drying process of wood. Internal pressures cause an array of radial and circular cracks to form within the inner parts of the wood, resulting in a honeycomb pattern texture.

4. Evaluation of deformation

The thickness at points A and B at the four edges of the two halves (newly exposed surface) were measured using a digital calliper, and the differences between the thickest (A) and the thinnest (B) sizes for each of the four positions were then determined (Figure 1). Mean values of the four differences, the thickest and thinnest (A-B) for the edge of each sample were assessed and classified as a cross-sectional deformation based on the prescribed classification (Table 1).



A: The portion thickest at the edge
B: The portion thinnest 1-2 cm apart from the edge

Figure 1. Method for evaluating deformation on the section

5. Determination of initial temperature, wet-bulb depression and final dry-bulb temperature

After the determination of sample scores for various defects (defects degrees), the respective drying parameters, such as initial dry-bulb temperature, initial wet-bulb depression and final dry-bulb temperature, were chosen from the predetermined chart (Table 3) prescribed for the level of checks, deformation, and honeycombing.

Selection of schedules for moisture content, dry-bulb temperatures and wet-bulb depression

Due to the lack of accepted schedules exclusively for coconut palm wood, appropriate schedules for moisture content, dry-bulb temperatures and wet-bulb depression were chosen by considering high-density coconut palm wood under the hardwood category and medium-density coconut palm wood under the category of softwood, respectively. Based on the parameters such as initial and final dry-bulb temperature, initial wet-bulb depression and initial moisture content, the corresponding schedules were selected from the Table prescribed by F.P.L. in Madison U.S.A (Simpson, 1991).

1. Determination of Relative Humidity (RH) and Equilibrium Moisture Content (EMC)

The relative humidity and equilibrium moisture content corresponding to dry-bulb and wet-bulb

temperatures were estimated using a Psychrometric Chart (Simpson, 1991).

Table 3. Classification of Initial DBT, Initial WBD Final DBT based on level of checks, deformation, and honeycombing

Variety of defecet	Drying condition	Defect degrees			
		1	2	3	4
I. Surface check	Initial DBT °C	70	65	60	55
	Initial WBD	6.5	5.5	4.3	3.6
	Final DBT °C	95	90	85	80
II. Deformation	Initial DBT °C	70	66	58	54
	Initial WBD	6.5	6	4.7	4
	Final DBT °C	95	88	83	80
III. Honeycomb	Initial DBT °C	70	55	50	49
	Initial WBD	6.5	4.5	3.8	3.3
	Final DBT °C	95	83	77	73

Drying schedule test

The kiln treatment was designed after quick drying tests. The highest score was selected from each type of drying defect (surface cracking, end splitting, honeycombing and deformation), and the treatment schedules were developed for each highest score based on the Terazawa (1965) method. The developed treatment schedules were imposed in a convection kiln to determine the best schedule suited for high-density and medium-density coconut palm wood. A total of forty samples were used for each treatment.

Results and Discussion

The study investigated the physical properties of coconut palm wood in order to standardize moisture content-based kiln seasoning schedule for high-density and medium-density coconut palm wood under the prevailing local climatic conditions (Average daily high temperature of 32°C and relative humidity of 60-67 %).

Physical properties of coconut palm wood

1. Basic density and Pilodyn Pin Penetration Depth (PPD)

Basic density values ranged from 214.83 kg/m³ to 977.19 kg/m³ for the coconut palm wood samples. The pilodyn penetration depth was recorded as 0 to 11 mm for high-density coconut palm wood, 12 to 35 mm for medium-density, and 38 to 42 mm for low-density coconut palm wood. Regression analysis by considering density as the dependent variable and PPD as the independent variable showed a linear relationship (Figure 2). With a significant R^2 value of 0.94, the analysis revealed a strong linear relationship between density and pilodyn penetration depth (PPD). This suggests that PPD can be a reliable predictor of density in coconut palm wood within the tested range. The specific equation for this relationship is as follows:

$$Y = -0.02\ (X) + 1.08$$

An inverse relationship is observed between pilodyn penetration depth (independent variable) and density (dependent variable). This variation from the core of the trunk to the dermal area can be attributed to several factors: (1) the number of vascular bundles (VBs) in the trunk, (2) the dimensions of the cell walls of vascular bundles, and (3) the cell wall thickness of the parenchyma, which acts as the ground tissue of timber. These factors contribute to the findings of Fathi & Frühwald (2014) that the density of palm wood increases from the inner core wood to the outer dermal wood, unlike other timber species. The density variation certainly affects coconut palm wood's strength and drying properties.

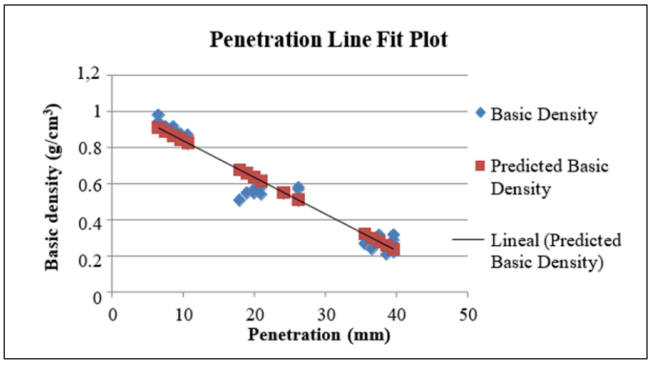


Figure 2. Relation between basic density (g/cm+) and penetration depth (mm) coconut palm wood

2. Moisture content

Moisture content in the wood is one of the key factors in the utilization of coconut palm wood. The higher moisture content in coconut palm wood makes it more susceptible to mold and fungi. This is mainly attributed to the non-homogenous nature of palm wood, as stated by Killmann (1983). The moisture content of freshly cut coconut palm wood samples showed significant variation between different density classes. The mean moisture content for high-density coconut palm wood was 52.67 %,

while a higher value of 103.96 % was observed for medium-density coconut palm wood. The moisture content profile showed a similar trend as that of dicotyledon wood in green conditions, in which the percentage moisture content values decreased drastically with increased wood density. This may be due to the higher number of parenchymatous cells in medium-density wood and the higher number of fibrous bundle caps in high-density coconut palm wood. The study of Bakar et al. (2013) also goes in tune with the present findings.

3. Volumetric shrinkage

Results on volumetric shrinkage of high, medium, and low-density coconut palm wood are presented in Table 4. Volumetric shrinkage ranged from 7.68% to 12.86% for high-density coconut palm wood, with a mean of 9.90%. For medium-density coconut palm wood, the volumetric shrinkage ranged from 9.03% to 13.74%, with a mean of 11.01%. The range of volumetric shrinkage for low-density coconut palm wood was 9.14% to 20.27%, with a mean of 12.03%. Interestingly, despite variations in density, no significant differences were observed in volumetric shrinkage across the wood classes. This may be attributed to the higher proportion of soft tissues within the lower-density samples. Richolson & Swarup (2007) reported similar shrinkage values for varying density classes of coconut palm wood.

Table 4. Mean physical properties of coconut palm wood of different density classes

Density classes	Moisture content (%)	Volumetric shrinkage (%)
High-density	52,67 ± 1,3[a]	9,90 ± 0,53
Medium-density	103,95 ± 0,83[b]	11,01 ± 0,49
Low-density	186,54 ±1,2[c]	12,03 ± 1,04
P Value	<0,001**	0,140[ns]

** significant at 1per cent level and 'ns' indicate non-significant

Susceptibility to drying defects

The results obtained from the quick drying test are shown in Table 5. It includes the types of defects observed, the maximum score obtained for each defect, and drying parameters (Initial DBT, Initial WBD, and Final DBT) for high-density and medium-density coconut palm wood. Among the defects, surface cracking and end splitting were found to be more severe in both high- and medium-density wood samples during the initial stages of the test. However, these defects became less noticeable in the final drying stages (Plate 1).

Kiln seasoning schedules were chosen based on the severity of the observed defects. Four unique schedules (KSH1, KSH2, KSH3, and KSH4) were selected for high-density wood, while three schedules (KSM1, KSM2, and KSM3) were chosen for medium-density wood. Since the score obtained for initial surface checks (Surface cracking and end splitting) of the medium-density samples were the same, it was considered a single treatment.

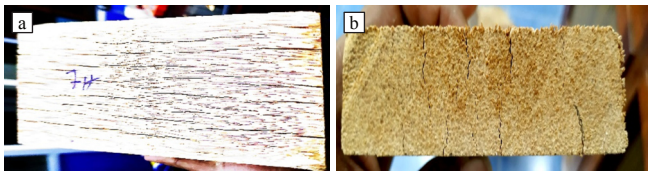


Plate 1. (a) Surface checks (b) End checks at the initial stages of quick drying test

Table 5. Drying schedule treatments used in the convection kiln to determine the best drying schedule for high and medium-density coconut palm wood

Kiln seasoning schedule treatment	Defect Observed	Max. score obtained	Initial DBT (°C)	Initial WBD (°C)	Final DBT (°C)
c	Surface cracking	8	45	1,8	79
KSH2	End splitting	7	47	2,0	80
KSH3	Honey-combing	3	50	3,8	77
KSH4	Defor-mation	4	54	4,0	80
KSM1	Surface cracking, End splitting	7	47	2	80
KSM2	Honey-combing	3	50	3,8	77
KSM3	Defor-mation	5	50	0,6	77

KSH denotes- Kiln Seasoning schedule for High-density coconut palm Wood

KSM denotes- Kiln Seasoning schedule for Medium-density coconut palm Wood

The highest degree of surface cracking observed in high-density wood was 8, while medium-density wood reached a maximum score of 7. The increased severity of defects in coconut palm wood is attributed to variations in moisture content and anatomical orientation of tissues. The quick drying defects distinctly displayed the higher

susceptibility of high-density coconut palm wood to defects compared to medium-density wood. This could be explained by the rigid tissue composition in high-density wood, which restricts free moisture diffusion during the drying process.

Plate 2. 25 mm thick coconut palm planks stacked in the convection Kiln

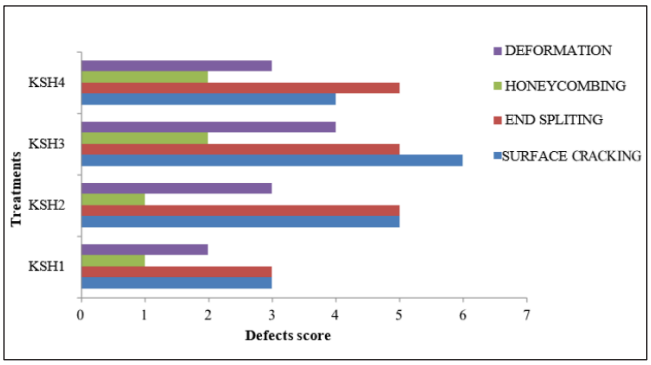


Figure 3. The treatment wise defects scores obtained for high-density coconut palm wood

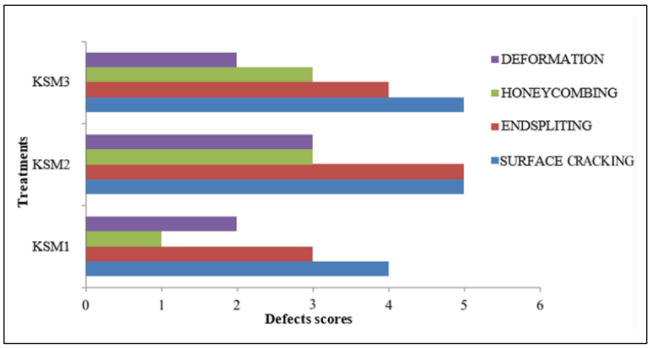


Figure 4. The treatment wise defects scores obtained for medium-density coconut palmwood

Testing of drying schedule

Treatment schedules were applied to 25 mm thick planks of coconut palm wood after stacking them in a drying chamber (Plate 2). The Terazawa (1965) scale was used to evaluate and select the most effective drying schedule. Figures 3 and 4 illustrate the results of seasoning schedule treatments for high-density and medium-density coconut palm wood, respectively. These figures depict the degrees of defects observed in the wood when subjected to various drying schedules in a convection kiln. For high-density wood, treatment KSH1 resulted in the least cracking, splitting, honeycombing, and deformation compared to the other schedules. Similarly, KSM1 proved to be the most effective treatment for medium-density wood due to minimal defects.

Table 6. Kiln drying schedule for high-density coconut palm wood

Moisture content (%)	DBT (°C)	WBT (°C)	WBD (°C)	RH (%)	EMC (%)
60-40	45	43	2	87	18
40-35	45	42	3	84	16
35-30	45	40	5	82	15
30-25	50	42	8	64	10
25-20	55	37	18	38	6
20-15	60	30	30	38	6
15-10	80	50	30	26	3

EMC = Equilibrium moisture content

Table 7. Kiln drying schedule for medium-density coconut palm wood

Moisture content (%)	DBT (°C)	WBT (°C)	WBD (°C)	RH (%)	EMC (%)
110-70	50	48	2	88	18
70-60	50	47	3	85	16
60-50	50	45	5	74	13
50-40	50	42	8	62	10
40-35	50	39	11	49	8
35-30	50	36	14	40	7
30-25	55	38	17	35	6
25-20	60	38	22	25	4
20-15	65	43	22	24	4
15-10	80	50	30	24	3

Kiln drying schedule

Kiln drying schedules were developed based on the initial moisture content of the wood. The average initial moisture content was 53% for high-density and 104% for medium-density coconut palm wood. In order to obtain satisfactory drying, less severe schedules were chosen, particularly for high-density wood, which is

Figure 5. Relation between moisture content and drying rate of high-density coconut palm wood

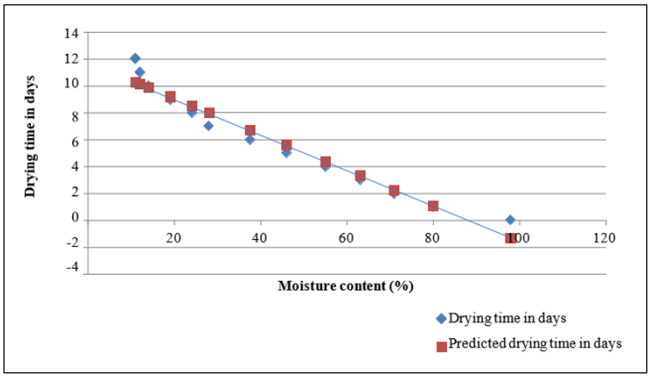
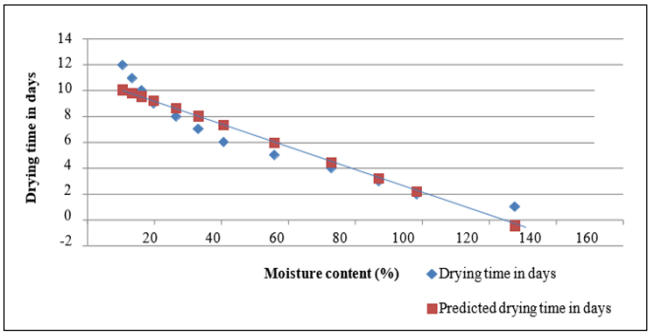


Figure 6. Relation between moisture content and drying time of medium-density coconut palm wood



more susceptible to defects during drying. The most recommended kiln drying schedule for 25 mm thickness high-density coconut palm wood was the schedule with initial DBT of 45°C (Relative humidity 87%), WBD of 2°C and final dry-bulb temperature of 80°C. Whereas, for medium-density coconut palm wood, with its lower susceptibility to defects observed in quick drying tests, a slightly more aggressive schedule (initial DBT 50°C) was found to be most effective. This difference can be attributed to the gradual moisture diffusion capacity of the medium-density wood during the drying process. Nine stages for high-density wood and 12 stages for medium-density wood are required. The detailed drying schedules for high and medium-density coconut palm wood are presented in Tables 6 and 7, respectively.

Kiln drying time

The period required for attaining equilibrium moisture content (EMC: 10 – 15 %) for each density class was also evaluated using 25 mm thick plank samples. The high-density coconut palm wood took 11 days to reach EMC, whereas medium-density wood took 12 days of kiln treatment to attain the prescribed equilibrium moisture content. The relation between moisture content and drying time of both high and medium-density coconut palm wood was plotted in Figures 5 and 6. The regression equation for high-density coconut palm wood is $Y = (-0{,}1335 \times X) + 11.737$. The R^2 for high-density coconut palm wood is 0.95. the regression equation for medium-density coconut palm wood is $Y = (-0{,}08503 \times X) + 11.0064$. The R^2 is 0.91 for medium-density coconut palm wood, where Y is the kiln drying time in days and X is h moisture content in percentage. The drying time plotted against the moisture content percentage for high- and medium-density coconut palm wood showed linear relationships.

Conclusion

Proper seasoning is a pre-requisite for producing quality wood products. The requirement of a scientifically proven drying schedule for lesser-known and underutilized timbers like coconut palm wood becomes important in the current context of raw material shortage for the timber industry. This study aimed to standardize moisture content-based kiln seasoning schedules for high-density and medium-density coconut palm wood. Kiln drying schedules were developed based on a quick drying test commonly used for hardwoods and softwoods. The baseline parameters, such as initial dry-bulb temperature, final dry-bulb temperature and the wet-bulb depression for high-density and medium-density coconut palm wood, were experimentally chosen by considering the major seasoning defects. Among the major seasoning defects, the most severe seasoning defect observed was surface checking. The schedules that could deliver dried timber with the least defects were evaluated based on the subsequent tests. The most recommended kiln drying schedule for 25 mm thickness high-density coconut palm wood was the schedule with initial DBT of 45°C (Relative humidity 87 %), WBD of 2°C and final dry-bulb temperature of 80°C, while, for medium-density wood, initial DBT 50°C (Relative humidity 88 %), WBD 2°C and final dry-bulb temperature 80°C.

These schedules can also find utility in the pursuit of further optimizing coconut palm wood planks of different sizes through the application of trial-and-error methods. Adapting the procedure outlined in this study also facilitates the development of drying schedules for coconut palm wood, characterized by different dimensions. The schedules developed have

good potential in industrial applications for mass production of dimensionally stable dried coconut palm wood lumber.

Acknowledgements

The authors wish to acknowledge the financial support of the Government of Kerala, India. The support and encouragement of the Director of Research, Kerala Agricultural University and the Dean, College of Forestry, Thrissur, Kerala, are gratefully acknowledged.

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DOI: 10.37833/cord.v40i.460
Coconut Research & Development, 2024, 40, 21-29

Detection of the Phytoplasma Associated with Lethal Yellowing-Type Syndrome of Coconut in Ghana in Three Weed Species

Egya Ndede Yankey[1*], Felix Bremang[1], Sebastian Andoh-Mensah[1], and Matthew Dickinson[2]

[1] Council for Scientific and Industrial Research – Oil Palm Research Institute (CSIR-OPRI), Sekondi, Ghana. P. O. Box 245, WS-001 5849
[2] School of Biosciences, University of Nottingham, Leicestershire, LE 12 5RD, UK

* Corresponding author. Email: ndedeyankey@yahoo.com

Abstract

The lethal yellowing-type syndrome of coconut in Ghana, locally called Cape St. Paul wilt disease (CSPWD) is considered as the foremost threat to the survival of the coconut industry in the country. The syndrome is associated with a phytoplasma belonging to the 16SrXXII-B subgroup. In Ghana, no alternative hosts of the phytoplasma have been identified. To identify alternative hosts of the phytoplasma associated with CSPWD, 21 plant species belonging to 16 plant families were sampled from within and around the vicinity of 10 CSPWD affected farms in the Western, Central and Volta Regions of Ghana. Nested PCR and sequencing using assays based on the 16SrRNA gene were used to detect the CSPWD associated phytoplasma in the plant species, *Laportea aestuans*, *Starchtarpheta indica* and *Pentodon pentandrus*. Removal of these non-coconut plant species will be incorporated into existing management strategies for CSPWD in Ghana. The plants will be further investigated for their role in the epidemiological cycle of the disease.

Key words: Coconut, Alternative hosts, phytoplasmas, lethal yellowing, Ghana

Introduction

Coconut is an important plantation crop that contributes significantly to agricultural productivity and the economy of Ghana. The crop is a source of employment and income to numerous rural coastal dwellers in Ghana and it is estimated that 5.4% of the national population are involved in the value chain of the crop (Abankwah et al., 2010). Ghana has a suitable climate and fertile soils for the cultivation of the crop. These factors have enabled the crop to be cultivated extensively along the coastal regions of the country. Ghana produces about 400, 000 metric tons of coconut annually from 75,000 hectares (FAO, 2019). The coconut industry in Ghana, however, is severely impacted by a devastating lethal yellowing-type syndrome (LYTS) locally called Cape St. Paul wilt disease (CSPWD) (Quaicoe et al., 2009; Yankey et al., 2018). CSPWD was first detected in 1932 in the South-eastern part of Ghana and has spread to all major coconut growing regions to become the foremost factor impacting the coconut industry in Ghana (Nkansah Poku et al., 2009; Ofori & Nkansah-Poku, 1997).

LYTS are associated with phytoplasmas (Dollet et al., 2009; Myrie et al., 2022; Pilet et al., 2019). Phytoplasmas are specialized plant pathogens that belong to the class Mollicutes, which are bacteria lacking a cell wall (Bertaccini et al., 2014; Christensen et al., 2005; Lee et al., 2000). These microorganisms are minute in size and have a unique cell structure that

enables them to infect and survive within the phloem tissues of plants (Bertaccini et al., 2014; Razin, 2007). Phytoplasmas rely on insect vectors, such as leafhoppers, planthoppers, and psyllids, for their transmission between plants (Bertaccini, 2022; Weintraub & Beanland, 2006). Due to their unique characteristics and obligate intracellular lifestyle, phytoplasmas are unculturable in cell-free media, making them challenging to study and characterize in laboratory settings.

Phytoplasmas are classified using two parallel systems. One system is referred to as the 16Sr groups and is based on restriction enzyme digest profiles of the 16S rDNA and the other is the '*Candidatus* Phytoplasma' species system, in which phytoplasmas sharing less than 97.5% similarity of their 16S rRNA gene sequence may be ascribed to different '*Ca.* phytoplasma' species when they are characterized by distinctive biological, phytopathological and genetic properties (IRPCM, 2004). The taxon *Candidatus* phytoplasma palmicola corresponds to phytoplasmas of the group 16SrXXII (subgroup -A and -B) (Harrison et al., 2014). The phytoplasma associated with CSPWD belongs 16SrXXII-B subgroup (Harrison et al., 2014). This subgroup also contains the phytoplasma that is associated with LYTS in Cote D'Ivoire. Closely related to this subgroup of phytoplasmas is the 16SrXXII-A subgroup which contains phytoplasmas associated with LYTS in Nigeria and Mozambique (Bila et al., 2015; Harrison et al., 2014).

Using a ribosomal protein gene assay, a single nucleotide polymorphism (SNP) was identified that delineated the CSPWD phytoplasma into two strains (Pilet et al., 2011). The authors observed a geographic differentiation of the phytoplasma: one strain was found to be associated with the disease in the Central and Western regions of Ghana, while the other strain was associated with the disease in the Volta region of Ghana. Furthermore, sequence analyses based on the leucyl-tRNA-synthetase gene (*leuS* gene) of the phytoplasma confirmed the geographic differentiation of two strains in Ghana (Dickinson et al., 2019).

Using a multi-locus sequence typing scheme (MLST), Pilet et al. (2019) identified three main populations of '*Ca.* phytoplasma palmicola' in three African countries with LYTS of coconut (i.e., with Ghana, Nigeria, and Mozambique). Each country had a unique population; in Ghana, four distinct sequence types were observed. The MLST scheme underscored the limitation associated with using a single gene such as the 16SrRNA gene for detection of genetic diversity within phytoplasma groups. An updated MLST scheme has revealed three additional sequence types in Ghana (Pilet et al., 2022).

LYTS are characterized by a sequence of symptoms that progress from one stage to another (Dollet et al., 2009; Yankey et al., 2018). Symptoms observed in CSPWD-affected coconut palms include premature nut drop in bearing palms, discoloration, and necrosis of the inflorescence, yellowing, and drooping of fronds, typically starting from the lower and oldest fronds of the canopy and progressing upwards. As the disease progresses, more fronds become affected, ultimately resulting in a characteristic "wilted" appearance of the palm. At the terminal stages of the disease, the crown falls off leaving only the stipe standing (Dery et al., 2008; Dery & Philippe, 1997; Yankey et al., 2018). LYTS are thought to have a latent phase prior to the initiation of disease symptoms and infected palms typically die 3-5 months after the first symptoms are seen (EFSA Panel on Plant Health, 2017).

The known vectors of LYTS phytoplasmaa are either planthoppers, leafhoppers or psyllids (Gurr et al., 2016; Philippe et al., 2007). Infected planthoppers acquire the phytoplasma while feeding on infected coconut palms and subsequently transmit it to healthy coconut trees during feeding activities. The vector of CSPWD is unknown, although, the phytoplasma associated with the syndrome has been detected in some *Diostrobus* species (Derbidae) (Philippe et al., 2007, 2009). Transmission trials in these studies were inconclusive.

Several LYTS phytoplasmas have multiple hosts including various palm species and grass or weed hosts. These include *Pennisetum pedicillatum*, *Paspalum vaginatum*, *Stachytarpheta indica*, *Scoparia dulcis*, *Diplacrum capitatum* (Arocha et al., 2016) and *Manihot esculenta* (Kra et al., 2017) for CILY; *Boraassus aethiopum* and *Elaeis guineensis* for the 16SrXXII-A phytoplasma in Mozambique (Bila et al., 2015); *Emelia fosbergii*, *Synedrella nodiflora*, *Stachytarpheta jamaicensis*, *Cleome rutidosperma* and *Macroptilium lathyroides* for the phytoplasma associated with lethal yellowing (16SrIV) in Jamaica (Brown et al., 2008; Brown & McLaughlin, 2011).

Alternative host plants may act as long-term reservoirs for the pathogen even in the absence of coconut palms. They may subsequently harm replanting efforts by supplying inoculum for the spread of the disease. Understanding the transmission pathways of LYTS, including the role of alternative hosts will contribute to our knowledge of the disease's spread. This information will serve as a foundation for developing effective

Table 1. Plant species sampled from CSPWD affected sites

Region/Location		Disease status*	Plant species	Plant family	No. of samples prepared
Central Region					
1.	Nyinsin	Active	*Asystasia gangetica*	Acanthaceae	7
			Cyclosorus striatus	Thelypteridaceae	9
2.	Odotom	Active	*Aspila Africana*	Asteraceae	6
3.	Eduagyeikrom	Active	*Chromolaena odorata*	Asteraceae	14
4.	Abontrase	Active	*Malvastrum coromandelianum*	Malvaceae	4
			Heterotis rotundifolia	Melastomataceae	7
5.	Mankrong	Active	*Pentodon pentandrus*	Rubiaceae	10
			Laportea aestuans	Uriticaceae	10
6.	Kokoado	Devastated	*Synedrella nodiflora*	Asteraceae	8
7.	Duakyimasi	Active	*Scoparia dulcis*	Plantaginaceae	11
			Stachytarpheta indica	Verbanaceae	10
			Melanthera scandens	Asteraceae	14
Volta Region					
8.	Keta	Devastated	*Amaranthus viridis*	Amaranthaceae	5
			Carica papaya	Caricaceae	2
			Manihot esculenta	Euphorbiaceae	5
			Phyllanthus amarus	Phyllanthaceae	6
Western Region					
9.	Krofofrom	Active	*Synedrella nodiflora*	Asteraceae	9
10.	Anlo Beach	Devastated	*Canavalia rosea*	Fabaceae	11
			Styllosanthes sp.	Fabaceae	10
			Cassytha filiformis	Lauraceae	11
			Phyllanthus amarus	Phyllanthaceae	4
			Capraria biflora	Plantaginaceae	9
			Stachytarpheta indica	Verbanaceae	10
Total					**192**

management strategies to mitigate the impact of the syndrome on coconut plantations.

The epidemiology of CSPWD has long supported the hypothesis of the involvement of non-coconut plant species in the spread of the disease (Yankey et al., 2009). Previous attempts at finding alternative hosts of the phytoplasma associated with the syndrome in Ghana did not yield positive results despite screening of several dozens of grasses, shrubs, food, and tree crops (Yankey, 2012; Yankey et al., 2009). In the present work, we report the detection and identification of the phytoplasma associated with the syndrome in Ghana in three non-coconut plant species.

Materials and methods

1. Plant sampling

Plant sampling was carried out during a survey to determine the limits of spread of CSPWD in the major coconut growing regions of Ghana under the auspices of a European Union funded Tropicsafe Project (www.tropicsqafe.eu). The sampling was carried between August 2017 and June 2018 and spanned both the rainy and dry seasons in Ghana.

Non-coconut plant species were collected from within and around the vicinity of CSPWD affected farms in 10 locations in the Central, Volta and Western regions (Table 1). The sampling sites were either devastated by the disease or the disease was still active. In the devastated farms, most of the palms were dead from infection and there were only a few surviving palms, or the palms were at the late stages of the disease. In the active disease fields, the disease was still spreading and there were a number of palms which were yet to be affected by the syndrome.

For sampling, plant species reported to host the 16SrXXII-B phytoplasma in Ivory Coast and present in the sampling locations were collected. Consequently, plants such as *Stachytarpheta indica*, *Scoparia dulcis* (Arocha et al., 2016) and *Manihot esculenta* (Kra et al., 2017) were sampled. Plant species which showed

Table 2. Nested PCR and sequencing of positive test samples

Region/Location	Plant species	*No. PCR positive samples obtained in Ghana	**No. PCR positive samples obtained UoN, UK	Consensus positive tests	Phytoplasma positives by sequencing
Central Region					
Mankrong Junction	*Pentodon pentandrus*	4/10	2/4	2/10 (20%)	2
Mankrong Junction	*Laportea aestuans*	3/10	1/3	1/10 (10%)	1
Duakyimase	*Stachytarpheta indica*	1/10	1/1	1/10 (10%)	1
Total		**8**	**4**	**4**	**4**

* A sample represented DNA prepared from two individual plants.

** Only duplicate samples which gave positive results in Ghana were tested at the University of Nottingham (UoN) and the positive samples sequenced in the UK.

Figure 1. Plant species identified as hosts of the phytoplasma associated with CSPWD: (A) *Pentodon pentandrus* (Rubiaceae); (B) *Laportea aestuans* (Urticaceae); and (C) *Stachtarpheta indica* (Verbanaceae)

general symptoms of phytoplasma infection such as stunting, yellowing, and withering were also collected. Varying numbers of individual plants of each species were sampled depending on their abundance at the sampling site. Sample sizes ranging from 4 to 22 individual plants were collected. No specific attempt was made to sample the same species across the sampling locations but rather a wide range of plant species were sampled.

The plant species were identified by a botanist (Mr. Francis Otoo, Crops Science Department) at the University of Cape Coast, Ghana (Table 1).

2. Sample preparation, DNA extraction and polymerase chain reaction

Collected plant samples were put into polythene bags and labelled. The samples were transported to the lab in coolers with ice packs. In the lab, the plant samples were thoroughly cleaned: each plant sample was swabbed with a paper towel soaked in 70% ethanol, to remove dust particles, insects and microorganisms that might be on the plant surfaces. Much of the lamina was then removed, leaving only a small strip around the midribs and veinlets. They were cut into small pieces (about 0.2 x 1 cm) for storage at -18°C until ready for use.

For DNA extraction, two individual plants of the same species from the same sampling location were pooled together to form a sample. Each sample was divided into two sub samples: DNA was extracted from one sample and used for the tests in Ghana and the other sample was stored away in a freezer at -20°C. One gram of plant tissue was ground in 5 ml of CTAB (20 mM EDTA pH 8.0, 1.4 M NaCl, 100 mM Tris-HCl pH 8.0, 2% Cetyl trimethylammonium bromide) and DNA was extracted using phenol: chloroform: isoamyl alcohol (25:24:1) and precipitated with isopropyl alcohol following the protocol of Daire et al. (1997).

Samples were assayed for the phytoplasma associated with CSPWD using nested PCR. A first round PCR was carried out using primers P1 (Deng & Hiruki, 1991) and P7 (Smart et al., 1996). The first round PCR products were diluted 20-fold and 1 µl used as template for nested PCR with primers G813f (Tymon et al., 1998) and GAKSR (Dollet et al., 2009). The P1/P7 PCR was carried using an initial denaturation of 94°C for 3 min, followed by 35 cycles of 94°C for 40 sec, 56°C for 40 sec, and 72°C for 1 min 40 sec and a final extension of

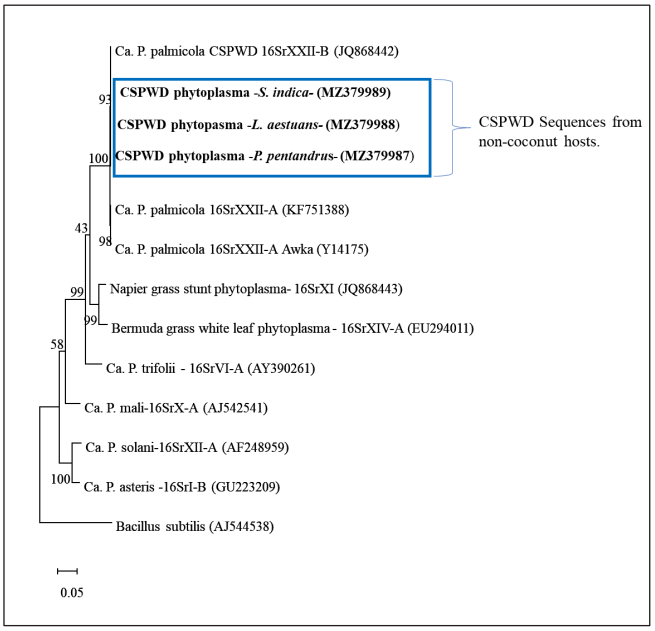

Figure 2. Phylogenetic tree based on the 16Sr gene sequences obtained from non-coconut plant species, *L. aestuans*, *P. pentandrus* and *S. indica* (boxed in blue and bold font) and reference 16Sr phytoplasma groups. GenBank accession numbers in parentheses.

72°C for 10 min. The same conditions were applied for the G813f/GAKSR assay except for the annealing temperature which was 53°C. Five microlitres of the PCR products were separated on 1% agarose gels in 1X TBE buffer at 100V and visualized in a UV trans-illuminator (Vilber Lourmat, France).

To avoid cross-over contamination in the nested PCR which could lead to avoid false positives results, dilution of the first round PCR products was carried using a different set of pipettes on a different lab bench. Also, only filter-fitted pipette tips were used to load the DNA template for the nested PCR.

For all samples, DNA extraction and PCR were first carried out at the lab at CSIR-OPRI (Ghana). Duplicates of the prepared plant samples of PCR positive test samples were shipped to the University of Nottingham (UK) for independent confirmation of the results. At the University of Nottingham, a Cox assay (Dickinson & Hodgetts, 2013) that amplifies plant DNA was to verify the efficacy of the DNA extraction before assaying for the presence of phytoplasma DNA using P1/P7 and G813f/GAKSR in nested PCR.

3. Sequence analysis

Consensus positive test samples between the labs in Ghana and the UK were sequenced directly. Sequencing was done at the University of Nottingham, UK. Sequences were compared to NCBI GenBank sequences using the BLAST algorithm (Altschul et al., 1990). The sequences were aligned, and sequence variations investigated using BioEdit, version 7. Phylogenetic and molecular evolutionary analyses were performed with MEGA version 11 (Tamura et al., 2021) using the Maximum Likelihood method and Tamura Nei model (Tamura & Nei, 1993) with 1,000 bootstrap replicates.

Results

1. Plant sampling and PCR analysis

Based on the criteria set for sampling, 21 plant species belonging to 16 plant families and composed of 192 individual plants were obtained for analysis (Table 1). The dominant plant family sampled was Asteraceae with five plant species.

In the PCR test, none of the samples produced a positive result with the primer pair P1/P7. In the nested PCR, eight samples gave positive results, yielding fragment sizes of approximately 875 bp. The samples comprised three samples of *Laportea aestuans* (Urticaceae) (3 of 10 samples), four samples of *Pentodon pentandrus* (Rubiaceae) (4 of 10 samples) and a sample of *Stachytarpheta indica* (Verbanaceae) (1 of 10 samples), as presented in Table 2.

Analysis at the University of Nottingham of duplicate samples which had given positive results in the laboratory in Ghana revealed only one out of the three samples of *L. aestuans* to be positive; two out of the four *P. pentandrus* samples produced positive results. The single sample of *S. indica* was confirmed to be positive for the phytoplasma (Table 2). The four positive tests between the two laboratories were therefore considered as consensus positive results. The Cox assay, however, produced an amplicon for the plant DNA in all eight samples. Both *L. aestuans* and *P. pentodon* were sampled from Mankrong while *S. indica* was sampled from Duakyimase, all in the Central region of Ghana. Pictures of the three plant species are shown in Figure 1.

The 16SrRNA gene sequences obtained from *P. pentandrus*, *L. aestuans* and *S. indica* were deposited in GenBank under accession numbers MZ379987, MZ379988 and MZ379989 respectively. In the phylogenetic analysis, sequences of the phytoplasma obtained from the non-coconut samples clustered with the sequence of the Ghanaian strain of the phytoplasma (16SrXXII-B) and this subgroup was confirmed to be distinct from the subgroup 16SrXXII-A (Figure 2).

Discussion

Phytoplasmas often have alternative hosts that serve as a store of the pathogens and contribute to the epidemiological cycles of the diseases (Alhudaib et al., 2009; Amiri Mazraie et al., 2023; Lee et al., 2003). The identification and elucidation of the roles of alternative hosts of LYTS will contribute to our understanding of the transmission pathways of the diseases. The identification of alternative hosts of the diseases will enable the development of integrated control strategies to mitigate the spread and devastation of LYTS.

In the present study, the phytoplasma associated with CSPWD was detected for the first time in two non-coconut plant species: *Pentodon pentandrus* (Rubiaceae) and *Laportea aestuans* (Urticaceae). It was also detected in *Stachytarpheta indica* (Verbanaceae) which has been previously reported in Cote D'Ivoire (Arocha et al., 2016). It is noteworthy to mention that another species of *Stachytarpheta* (*S. jamaicensis*) was reported as an alternative host plant of the LYTS phytoplasma (16SrIV) in Jamaica (Brown & McLaughlin, 2011). It therefore appears that the *Stachytarpheta* genera could have other potential hosts of LYTS phytoplasmas. This observation will serve as an important consideration in future studies. *Scoparia dulcis* and *Manihot esculenta* are two other species that have been reported as secondary hosts of LYTS in Cote D'Ivoire that were sampled in this study but with a negative result. *Manihot esculenta* (cassava) was screened for the CSPWD associated phytoplasma in previous studies (Yankey, 2012; Yankey et al., 2009) but with negative results albeit with only first round PCR. The crop is an important food crop which is often grown as an intercrop in coconut plantations in Ghana and the negative results is therefore welcome information for coconut farmers in Ghana.

The phytoplasma detection rates recorded in this study were 10, 20 and 10 % for *S. indica*, *P. pentodon* and *L. aestuans* respectively. Although, a detection rate of 20% has been reported for *Diplacrum capitatum* and *Paspalum vaginatum*, secondary hosts of the LYTS in Cote D'Ivoire, relatively higher rates of 60% have also been reported for species such as *S. indica* and *Pennisetum pedicellatum* of the same phytoplasma (Arocha et al., 2016). Detection rates of below 20% were also reported for *Emelia forsbegii* and *Synedrella nodiflora* in Jamaica (Brown et al., 2008). It therefore appears that the distribution of the LYTS phytoplasma in secondary hosts in the vicinity of LYTS affected fields does not follow any consistent pattern.

None of the samples produced a positive result with first-round PCR involving primer pair P1/P7. Previous studies to find secondary hosts of CSPWD in Ghana that tested dozens of plant species also used single round PCR and did not obtain any positive tests (Yankey, 2012; Yankey et al., 2009). Nested PCR is often fraught with cross-over contaminations that results in false positive results, because of the numerous handling steps. Measures such as using filter-fitted pipette tips for loading the template DNA and a dedicated set of pipettes were therefore put in place to minimize the risk of such contaminations in this study. Again, positive results obtained in the tests in Ghana were independently verified at the University of Nottingham, UK by repeating the processes from DNA extraction to the PCR tests. While this was helpful, two positive tests obtained in Ghana were not confirmed in the tests in the UK. This could have been an incidence of cross-over contamination or a heterogenous distribution of the phytoplasma in the samples. The use of nested PCR rather than single round PCR to detect the CSPWD phytoplasma suggests that the titres of phytoplasma in non-coconut plant hosts are very low as compared with those found in coconut. The CSPWD associated phytoplasma is readily amplified with first round PCR in coconut samples (Yankey et al., 2011). Similar investigation in Cote D'Ivoire and Mozambique also used nested PCR to detect phytoplasma DNA in non-coconut host plants (Arocha et al., 2016; Bila et al., 2015). Single nucleotide polymorphisms (SNPs) have been reported for some genes of '*Ca.* Phytoplasma Palmicola' from Ghana but no SNPs were found in the 16SrRNA gene (Dickinson et al., 2019; Pilet et al., 2011). This study employed a 16Sr RNA gene-based assay and therefore the relative low detection rates observed may reflect the small sample sizes of plants analyzed rather being a result of false negative diagnosis. Increasing the sample sizes of the plant species tested may be useful in improving the detection rates in future studies.

The phylogenetic analysis showed the sequences amplified from the three non-coconut hosts to cluster with CSPWD phytoplasma sequences (16SrXXII-B) obtained from GenBank. The cluster was distinct from the 16SrXXII-A subgroup which formed a separate cluster and thus confirming the distinction between the two subgroups (Harrison et al., 2014).

Current management strategies for CSPWD include removal and burning of infected palms and replacing them with disease resistant materials (Nkansah-Poku et al., 2005; Nkansah Poku et al., 2009); regular phytosanitary

monitoring and adherence to recommended cultural practices (Dery et al., 2008). The three non-coconut hosts identified in this study are weeds in coconut plantations. Their removal from coconut plantations will be added to the recommendations. Effective weed control schemes such as regular field maintenance and the use of cover crops such as *Pueraria phaseoloides* or *Mucuna brataeta* will also be helpful in suppressing these and other weeds in coconut farms. Further studies on these plant species are expected to shed more light on their in the epidemiological cycle of CSPWD.

Conclusion

Phytoplasmas are obligate pathogens that always require living hosts for their survival. Phytoplasmas are associated with LYTS which are transmitted by insect vectors that harbour the pathogens in their bodies. The identification of secondary hosts of the phytoplasmas associated with CSPWD is an important step in understanding the transmission pathways of the disease. A wider range of plant species with larger sample sizes may help to find other alternative hosts of the CSPWD associated phytoplasma and improve their detection rates.

Acknowledgments

We gratefully acknowledge the financial support for this research by European Union's Horizon 2020 research and innovation programme under, project "Insect-borne prokaryote-associated diseases in tropical and subtropical perennial crops" TROPICSAFE grant agreement No. 727459.

Disclosure

This manuscript has not been published and is not under consideration for publication elsewhere. The authors have no conflict of interest to disclose.

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DOI: 10.37833/cord.v40i.483
Coconut Research & Development, 2024, 40, 31-39)

Creamed Coconut Testa and Creamed Coconut as Substitutes for Coconut Milk in Culinary Uses

K. G. S. N. Kumari[1], B. S. K. Ulpathakumbura[1], K. M. R. U. Gunarathna[1], O. M. Lai[2] and J. M. N. Marikkar[1*]

[1] National Institute of Fundamental Studies, Hanthana Road, Kandy, Sri Lanka
[2] Department of Bioprocess Technology, Universiti Putra Malaysia 43400 UPM Serdang, Selangor D.E., Malaysia

* Corresponding author. Email: nazrim.ma@nifs.ac.lk

Abstract

Coconut milk plays a crucial role in preparation of curries and other savoury dishes in Sri Lanka. While squeezing grated coconut manually, there is a wastage of coconut as well as coconut testa which is a significant by-product of coconut processing industries. This study aimed to evaluate the potential of utilizing creamed coconut (CC) and creamed coconut testa (CCT) as a viable substitute for coconut milk in culinary uses. To attain this objective, the nutritional composition of CC and CCT was determined and sensory evaluation was undertaken to test the suitability of these two products as cooking medium on a potato curry using a group of thirty semi-trained panelists. Four formulations of CCT incorporated potato curry were prepared coded as F1 (CCT:water = 1:9), F2 (CCT:water =1:4), F3 (CCT:water = 3:7) and F4 (CCT:water = 2:3). Besides, P1 (CC:water = 1:9), P2 (CC:water = 1:4), P3 (CC:water = 3:7), P4 (CC:water = 2:3) were coded as the four formulations of potato curry, incorporating CC. The analysis revealed that fat, crude protein and carbohydrate in CC was higher than CCT except crude fiber content. However, there was no significant ($p > 0.05$) difference in ash and moisture contents. According to sensory evaluation, F1 (CC: water = 1:9) and P2 (CC:water = 1:4) were identified as the most preferred potato curry formulations incorporating CCT and CC respectively. In conclusion, there was a potential of utilizing and maximizing coconut meat and testa as a viable substitute for coconut milk in culinary applications.

Key words: Creamed coconut, creamed coconut testa, proximate composition, potato curry formulations, sensory attributes

Introduction

Coconut (*Cocos nucifera* L.) is a perennial crop of the tropics grown in more than 80 countries (Arunachalam, 2012). For the past several decades, it has held a significant position within the plantation sector of Sri Lanka. At present, it represents roughly about 12% of the country's overall agricultural production. Apart from a food commodity, coconut fruit also has numerous medical benefits; the tender coconut nut water being naturally sterile could be source of an oral rehydration medium to keep the body cool. Likewise, the bulk of the matter in coconut oil is triacylycerols (> 98%) (TAG) that are composed of medium chain fatty acids in high proportions. When hydrolyzed by pancreatic lipase, TAG molecules are converted to monolaurin, which are known to impart health benefits, including anti-bacterial, anti-viral, and anti-HIV activities (Deen et al., 2020). The flesh of the coconut fruit called coconut kernel, is rich in fat, protein, fiber, and carbohydrate (Appaiah et al., 2014). Generally, coconut kernel is used to make various products such as coconut oil, desiccated coconut, virgin coconut oil, coconut milk powder and coconut milk (Marasinghe et al., 2019). Coconut milk extracted from coconut kernel is a common ingredient in daily culinary preparations that include vegetables, meats, fishes, and various baked products. Traditionally,

coconut milk is prepared at home by adding water to grated coconut meat and squeezing it out to extracting milk (Suyitno, 2003). Squeezing grated coconut for milk is a common practice even among small householder industries (Dewi et al., 2019). In fact, this method of milk extraction leads to considerable amount of nutrients of coconut remaining in the residue portion being lost and discarded as waste. Owing to the escalation of the demand for coconut in the local market, this kind of losses and wastage during the house hold consumption have to be stopped using an alternative product.

The white kernel of the coconut fruit has a thin brown colour outer-covering which is called coconut testa (CT). As the coconut reaches the maturity, the thickness of the testa also increases to give it a brown colour. The testa of coconut is removed by paring the coconut flesh during the preparation of products such as desiccated coconut, coconut milk and virgin coconut oil. Thus, CT becomes a by-product of the coconut processing industry (Appaiah et al., 2021). Previous investigations showed that approximately 18% (w/w, on a wet basis) of the entire coconut kernel lost during removal of testa (Gunarathne et al., 2021). According to some prior estimates, approximately 6,500 kilograms of wet CT are generated from 100,000 nuts of the Sri Lankan tall variety (Perera et al., 2014). Despite the edible nature of CT, its complete utilization as a food has not yet been fully realized. Currently, CT is only used for low-grade oil extraction and the residue is left as a feedstock for animals. In order to augment the commercial use of CT, research initiatives were recently undertaken, which showed the presence of beneficial active compounds such as polyphenols, flavonoids with antioxidant properties along with dietary fiber and essential minerals (Fareed et al., 2022; Gunarathne et al., 2021).

Nowadays, Sri Lanka has experienced a significant surge in coconut prices in the local market due to various challenges. Hence, the cost of fresh coconut in the form of milk is escalating day by day. The aim of this research is to minimize the wastage during squeezing of grated coconut for milk extraction through utilizing the CT in coconut processing industries. In this study, preparation of creamed coconut and creamed coconut testa was undertaken to use them as viable alternatives for coconut milk in culinary applications. According to a previous report, CC is found to have 65% fat, 8% protein, 4% crude fiber and 17.5% other carbohydrates (Marikkar & Madurapperuma, 2012) and as such using it directly for culinary purposes is not feasible. Hence, this study focused on a sensory evaluation to work out a way to use these two products as alternative cooking medium for a potato curry.

Materials and Methods

Materials and Sampling

Samples of mature coconuts were collected from Kandy market, Sri Lanka and de-husked.

Methods

Preparation of CC and CCT: De-husked coconuts were split-opened to recover coconut kernel and the testa separately. These were disintegrated into small particles and subjected to oven drying at 80°C temperature for 8 hours to reduce their moisture contents to below 5% using a forced air-drying oven (Biobase, model - BOV-V230F, China). The dried samples were removed from the oven and grounded using a grinding mixer (Model MG 2053, India) until a thick cream was formed.

A proximate compositional analysis was performed to assess the nutritional values of CC and CCT in terms of nutrients such as moisture, ash, fat, proteins, carbohydrates etc.

Proximate compositional analysis: Determinations of the moisture, ash, protein and fat contents related to proximate composition were performed in accordance with the procedures described in AOAC International (2000) manual. The carbohydrate content of the flour was calculated by difference [100 - (crude protein + crude fat + ash + moisture+ crude fiber)]. The results of the proximate composition are given in Table 2.

Moisture: The moisture contents of samples were determined according to AOAC International (2000) Specification (method 934.01). An empty petri dish set was dried in hot air oven at 105°C for 3 hours and transferred to a desiccator to cool. The empty petri dish set was weighted. About 3g of sample was weighed into each petri dish and sample was spread uniformly. The Petri dish with sample was placed in the hot air oven for 3 hours at 105°C. It was transferred to a desiccator to cool and the whole weight of petri dish and its dried sample were measured, following formula was used to calculate the moisture content:

$$\text{Moisture content} = \frac{\text{Initial weight of sample - Final weight of sample}}{\text{Initial weight of sample}} \times 100$$

Table 1. Different potato curry formulations of creamed coconut testa

Curry Variant	CCT (ml)	Water (ml)	Potato (g)	Salt (g)	Turmeric Powder (g)	Chili Powder (g)	Curry Powder (g)	Cardamom (g)	Curry Leaves
F1	50	450	150	7	1	3	2	2	5
F2	100	400	150	7	1	3	2	2	5
F3	150	350	150	7	1	3	2	2	5
F4	200	300	150	7	1	3	2	2	5

Abbreviations: CCT, creamed coconut testa; F1, formulation of CCT with water in 1:9 ratio; F2, formulation of CCT with water in 1:4 ratio; F3, formulation of CCT with water in 3:7 ratio; F4, formulation of CCT with water in 2:4 ratio

Table 2. Different potato curry formulations of creamed coconut

Curry Variant	CC (ml)	Water (ml)	Potato (g)	Salt (g)	Turmeric Powder (g)	Chili Powder (g)	Curry Powder (g)	Cardamom (g)	Curry Leaves
P1	50	450	150	7	1	3	2	2	5
P2	100	400	150	7	1	3	2	2	5
P3	150	350	150	7	1	3	2	2	5
P4	200	300	150	7	1	3	2	2	5

Abbreviations: CC, creamed coconut; P1, formulation of CC with water in 1:9 ratio; P2, formulation of CC with water in 1:4 ratio; P3, formulation of CC with water in 3:7 ratio; P4, formulation of CC with water in 2:4 ratio

Fat: Crude fat contents of samples were determined by Soxhlet method according to the specifications of AOAC International (2000) (method 963.15). About 1.00 g of sample was weighted to paper filter and was wrapped. Sample was taken into extraction thimble and transferred into Soxhlet. Dichloromethane was filled to about 50 ml into the round bottom flask and it was taken on the heating mantle. Soxhlet apparatus (FAT-06A) was connected, and the water was turned on to cool them and then the heating mantle was switched on. The sample was heated for about 14 hours (heat rate of 150 drop/min).

The solvent was evaporated by using the same heating mantel. The round bottom flask was transferred to the desiccator to cool. The flask and its dried content were reweighted. Fat content was determined according to the following formula:

$$\text{Fat content} = \frac{\text{Weight of the flask with fat - Initial weight of the flask}}{\text{Weight of the sample}} \times 100$$

Ash: Total ash contents of samples were determined according to the specifications of AOAC International (2000) (method 923.03). The crucible was placed in furnace at 550°C. It was cooled in a desiccator for 30 minutes. Crucible was weighed and about 5 g of sample was added. Crucible was placed in muffle furnace (S/N FH128120900) at 550°C for 24 hours. Crucibles were removed from muffle furnace and were placed in the desiccator to cool. Final weights of the crucibles were weighed. The following formula was used in the determination of ash content:

$$\text{Ash content} = \frac{\text{Weight of crucible with ash - Weight of crucible}}{\text{Initial weight of sample}} \times 100$$

Protein: Crude protein contents of samples were determined by Kjeldahl method according to AOAC International (2000) (method 960.52). About 1 g of sample was weighed and its weight was recorded. The weighed sample was placed in a digestion tube. Five grams of Kjeldahl catalyst and 200 ml of concentrated sulphuric acid were added to each tube containing the sample. The flasks were placed in inclined position and gently heated until the frothing ceases. It was boiled briskly until the solution cleared. The solution was cooled, and added 60 ml distilled water. Flask was connected immediately to digestion bulb through the condenser with the tip of the condenser immersed in a standard solution of boric acid. When NH3 reacting with boric acid, the solution in the receiver turned from red-violet color to green color due to boric acid turning to borate anion (basic medium). The borate anion formed was titrated with a standard solution of HCl. A reagent blank was run separately to subtract the reagent nitrogen from the sample nitrogen. The following formula were used in determining the protein content:

Table 3. Proximate composition of creamed coconut and creamed coconut testa

Samples	Moisture (%)	Ash (%)	Fat (%)	Protein (%)	Crude fiber (%)	Carbohydrate (%)
CC	0.84 ± 0.01^{a}	1.46 ± 0.02^{a}	68.32 ± 0.29^{b}	8.21 ± 0.00^{b}	12.05 ± 0.00^{a}	9.12 ± 0.00^{b}
CCT	0.83 ± 0.01^{a}	1.54 ± 0.05^{a}	65.63 ± 0.51^{a}	8.11 ± 0.00^{a}	16.00 ± 0.00^{b}	7.89 ± 0.00^{a}
CL	NS	NS	*	*	*	*

Each data in the table represents mean of triplicate analyses. Means in the same column bearing different superscripts are significantly ($p<0.05$) different from each other. Abbreviations: CL, confidence level; NS, not significant; *, ($p<0.05$); CC, creamed coconut; CCT, creamed coconut testa.

$$\text{Total nitrogen percentage} = \frac{(\text{Simple titrate} - \text{blank titrate}) \times \text{Molarity of HCL} \times 14 \times 100}{\text{Weight of sample} \times 1{,}000} \times 100$$

$$\text{Protein percentage} = \text{Total nitrogen percentage} \times 6.25$$

Crude Fiber: Crude fiber contents of samples were determined according to the AOAC International (2000) specification (method 962.09). One gravimetric approach, the crude fiber method, measures the organic food residue that is left after sequential digestion with 0.255N sulfuric acid and 0.313N sodium hydroxide solution, followed by overnight oven drying at 104°C and lastly exposed to 3 hours igniting at 600°C in a muffle furnace. The following formula was used in determination of crude fiber content.

$$\text{Crude fiber content} = \frac{(\text{Weight of sample before ashing} - \text{Weight of sample after ashing}) \times 100}{\text{Weight of sample}} \times 100$$

Carbohydrate: The following formula was used in determination of carbohydrate contents of samples.

$$\text{Carbohydrate content (\%)} = 100 - \%\,(\text{Moisture} + \text{Ash} + \text{Protein} + \text{Fat} + \text{Crude Fiber})$$

Formulation of potato curry incorporating creamed coconut and creamed coconut testa: Creamed coconut and creamed coconut testa samples were diluted with water to find the best acceptable formulations of CCT/CC: water. Initially, four formulations were prepared by diluting CCT/CC with water at 1:9, 1:4, 3:7 and 2:3 ratios using both products separately. As shown in Table 1 and 2, four distinct formulations of potato curry were prepared by altering the ratios of CC/CCT to water in separate cooking pans while maintaining consistency in other ingredients. Initially, potatoes were boiled in a pressure cooker for about 5 minutes. The boiled potatoes were peeled and diced into small cubes and set aside. Subsequently, formulation which prepared by diluting CCT with water at 1:9 ratio was added into cooking pan and mixed well under low heat. After that, turmeric powder, chili powder, curry powder, salt and cardamom were added to the pan according to amounts as mentioned in Table 1 and 2, and stirred well for about 3 minutes. The boiled, diced potatoes were introduced to the mixture in the cooking pan. After adding the curry leaves, the dish was cooked for 15 minutes until the curry become thicken. As shown in Table 1 and 2, the same procedure was repeated for 1:9, 1:4, 3:7 and 2:3 ratios of other formulations of both CCT and CC product.

Sample size: 100 ml of CC and CCT were produced using 100g of dried coconut kernel and dried coconut testa separately. For the sensory evaluation purpose, 900 g of dried coconut kernel or dried coconut testa was required to preparation of 900 ml of either CC or CCT. The serving size of the curry per panelist was 30 ml. Based on this, the total requirement of CC/CCT for the formulated recipes for 30 panelists was determined as follows: (a) For creamed coconut testa curry series: F1 - 90 ml; F2 - 180 ml; F3 - 270 ml; F4 - 360 ml, (b) For creamed coconut curry series P1 - 90 ml; P2 - 180 ml; P3 - 270 ml; P4 - 360 ml.

Sensory Serving the sample: The samples were coded with three digits random numbers and served to the panelists in random order with serving size of 30 ml per sample with bread pieces. Curry samples were microwaved and freshly served among the panelists in each session of sensory evaluation.

Sensory Testing criteria: A preference ranking tests were performed using a group of thirty semi-trained panelists to select the most preferred formulation out of the potato curries incorporated with either creamed coconut or creamed coconut testa. The panelists were instructed to assign preference rank according to the ranking scale: 1: extremely preferred sample; 2: moderately preferred sample; 3: slightly preferred sample; 4: least preferred sample based on individual sensory attribute.

Statistical analysis: The data obtained from the sensory evaluation was statistically analyzed using Minitab 17.1 software package. Friedman test was performed to determine if there is a significant difference ($p < 0.05$) among median values obtained for

each sensory attribute of the four formulations. When a significant difference ($p < 0.05$) was detected in Friedman test, the Mann-Whitney test was performed to identify the significant difference ($p < 0.05$) between all possible combinations of formulations based on each sensory attribute.

Results and Discussions

Proximate composition of products

The proximate compositional analysis data of the creamed coconut and creamed coconut testa are given in Table 3. Except the ash and moisture contents, all the other parameters exhibited significant ($p < 0.05$) differences. Moisture content of food product is crucially important in determining its quality and shelf-life stability. In this study, the moisture contents of creamed coconut and creamed coconut testa were 0.84% and 0.83%, respectively (Table 3) but no significant ($p > 0.05$) difference was found between the two products. Though the fresh coconut flesh generally possesses high moisture content, the moisture of creamed coconut products was shown to drop drastically, resulting in the final products possessing a low moisture content. According to a previous study by Appaiah et al. (2014), the moisture contents of the whole copra, white copra kernel, copra testa, wet whole coconut, wet coconut white kernel, wet coconut testa were 4.30%, 3.80%, 4.00%, 42.20%, 43.50%, and 32.90%, respectively. Based on the studies of Belewu et al. (2014) and Beegum et al. (2022), the moisture contents of fresh coconut milk were 88.65% and 57.32%, respectively.

Lipid, sometimes referred to as dietary fat, is a key macronutrient that offers energy and essential fatty acids vital for numerous body functions (Raihana et al., 2015). Cushioning the organs, maintaining control of body temperature, and aiding in the absorption of fat-soluble vitamins are some of the functions of lipids. Apart from these, they act as building materials for cell structure as the majority of the cell membrane are phospholipids. Apart from these, various other functional attributes of coconut oil have already been discussed elsewhere in the literature (Deen et al., 2020). The fat content was found as the largest component of both creamed coconut testa (65.63%) and creamed coconut (68.32%). In fact, there was a notable variance in the fat content between creamed coconut and creamed coconut testa, showing significant difference ($p < 0.05$). According to Appaiah et al. (2014), the oil content of coconut testa was comparatively lower than that of the coconut kernel, in conformity with the findings of fat content of CC and CCT of this study (Table 3). The study by Appaiah et al. (2014) further reported that the fat contents of the copra as a whole, copra white kernel, copra testa, wet coconut whole, wet coconut white kernel, wet coconut testa were 59.80%, 63.60%, 59.00%, 37.00%, 38.80%, and 34.70%, respectively. Moreover, (Beegum et al., 2022) assessed the composition of coconut milk, revealing a fat content of 27.69% on a wet basis. On a comparative basis, the fat contents of CC, CCT and coconut milk were found to be in the ranking order of CC > CCT > Coconut milk. The high fat content of these products makes it necessary to go for a dilution while preparing coconut milk-based foods.

Ash is the inorganic residue that remains in food systems after the organic substance has either completely oxidized or ignited. Determination of the ash content of foods holds importance for various reasons. Apart from providing vital information towards the nutritional quality of foods, ash content might have helped to identify the distribution of major and trace minerals (deMan et al., 2018). The findings by (Marasinghe et al., 2019) already showed that Mn was the most prevalent mineral in coconut testa, followed by Zn and Cu. As shown in Table 3, the ash contents of creamed coconut and creamed coconut testa were 1.46% and 1.54%, respectively, but their difference was not significant ($p > 0.05$). The literature data regarding the composition of ash present either in CC or CCT remains scarce; previous research has explored only the ash content of both fresh coconut flesh and fresh testa. Appaiah et al. (2014) reported the ash contents of the copra whole, copra white kernel, copra testa, wet coconut whole, wet coconut white kernel, wet coconut testa were 1.40%, 2.10%, 1.40%, 1.00%, 0.90%, 0.70% respectively. Previously Dendy & Timmins (1974) and Chakraborty (1985) also conducted multiple studies, reporting the ash contents for mature coconut kernel as 1.30% and 1.10%, respectively. According to Beegum et al. (2022), the ash content of coconut milk was 2.84%. Upon analyzing the current and previous data, the ash content sequence observed among CC, CCT, and coconut milk remains consistent, with CC and CCT possessing similar amounts which are lower than that of coconut milk.

Protein represents the third essential macromolecule within food systems and is crucial to many biological functions of the human body. Determination of the protein contents of coconut-based products is significant as they play a vital role of fostering the body growth, upkeep of cells and tissues, acting as enzymes, transporters and regulators of diverse biological processes (deMan et al., 2018). The data depicted in

Table 4. Results of Friedman test along with the rank median of sensory attributes of different formulations of potato curry incorporated with creamed coconut testa

Formulation	Appearance	Aroma	Colour	Creaminess	Flavor	Overall acceptability
F1	1.12[a]	1.00[a]	1.00[a]	2.00[a]	1.75[a]	1.25[a]
F2	1.87[a]	2.00[a]	2.00[b]	1.00[a]	1.25[a]	1.75[a]
F3	3.12[b]	3.00[b]	3.00[c]	3.00[b]	3.50[b]	3.25[b]
F4	3.87[c]	4.00[c]	4.00[d]	3.00[b]	3.50[b]	3.75[b]
CL	***	***	***	***	***	***

Rank median bearing different superscriptions are significantly different from each other at 99% confident interval level (α = 0.01). Abbreviations: F1 potato curry prepared with 50 ml of creamed coconut testa with 450 ml of water; F2 potato curry prepared with 100 ml of creamed coconut testa with 400 ml of water; F3 potato curry prepared with 150 ml of creamed coconut testa with 350 ml of water; F4 potato curry prepared with 200 ml of creamed coconut testa with 300 ml of water.

Table 5. Results of Friedman test along with the rank median of sensory attributes of different formulations of potato curry incorporated with creamed coconut

Formulation	Appearance	Aroma	Colour	Creaminess	Flavour	Overall acceptability
P1	3.75[c]	3.25[b]	3.75[c]	3.50[c]	4.00[b]	4.00[b]
P2	1.25[a]	1.75[b]	1.25[a]	2.25[a]	2.00[a]	2.00[a]
P3	2.00[a]	2.25[a]	2.00[a]	2.25[a]	2.00[a]	2.00[a]
P4	3.00[b]	2.75[b]	3.00[b]	3.00[b]	3.00[b]	3.00[b]
CL	***	***	***	***	***	***

Rank median bearing different superscriptions are significantly different from each other at 99% confident interval level (α = 0.01). Abbreviations: P^1, potato curry prepared with 50 ml of creamed coconut with 45 ml of water; P^2 potato curry prepared with 100 ml of creamed coconut with 400 ml of water; P^3 potato curry prepared with 150 ml of creamed coconut with 350 ml of water; P^4 potato curry prepared with 200 ml of creamed coconut with 300 ml of water.

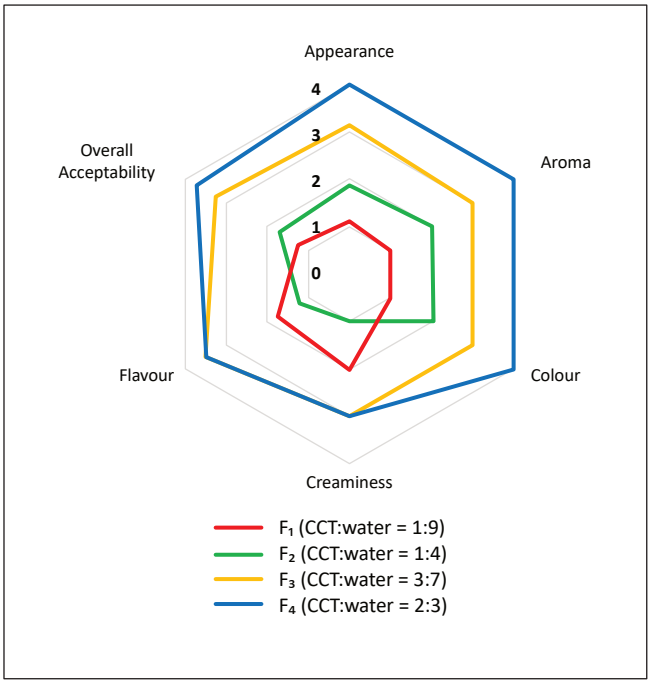

Figure 1. Radar chart depicting the sensory attributes of various potato curry formulations incorporating CCT

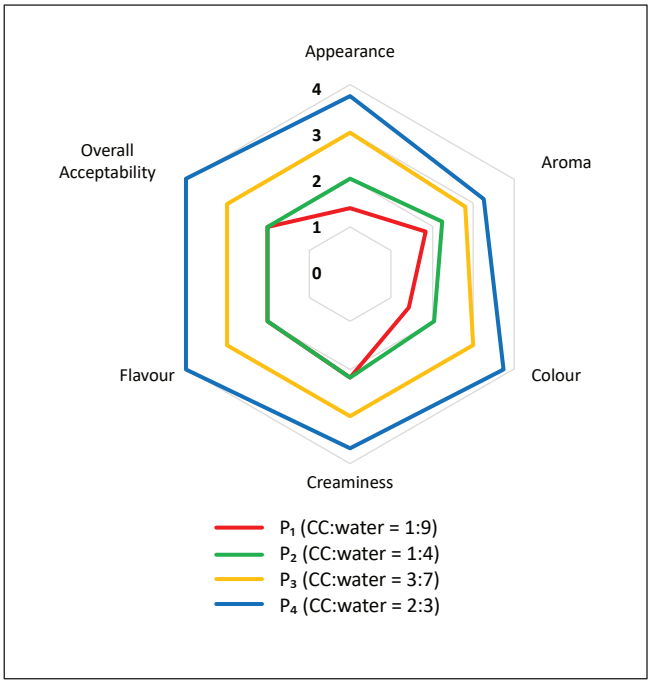

Figure 2. Radar graph for the sensory analysis median score values for various potato curry formulations incorporating creamed coconut

Table 3 indicates that the crude protein content of CC was 8.21%, while that of CCT was 8.11%. There was a statistically significant ($p < 0.05$) difference between the two products, with CC having the highest value. While literature data specific to the protein contents of creamed coconut testa are scarce, the availability of data on the protein content of the fresh coconut flesh and coconut testa exists. As evaluated by Appaiah et al. (2014), the protein content of the copra whole, copra white kernel, copra testa, wet coconut whole, wet coconut white kernel, wet coconut testa were 10.20%, 8.10%, 9.30%, 7.50%, 6.20%, 7.10%, respectively. In a separate study, Beegum et al. (2022) stated that coconut milk had a portion content of 6.79%, which was lower than those of CC and CCT.

The fiber in foods is actually a form of carbohydrate, which includes dietary fibers that are both soluble and insoluble. As a matter of fact, they provide a variety of health benefits. According to Table 3, the amounts of crude fiber in CC and CCT were 12.05% and 16.00%, respectively. There was a significant ($p < 0.05$) difference between them with CCT having the greatest value. There is hardly any literature data on the crude fiber content of creamed coconut or creamed coconut testa to compare the results of this study. In a previous study, Appaiah et al. (2014) showed that the cruder fiber contents of the whole copra, copra white kernel, copra testa, wet coconut whole, wet coconut white kernel, wet coconut testa were 7.00%, 6.60%, 11.60%, 14.30%, 11.70%, and 17.20%, respectively. Apart from this, Belewu et al. (2014) previously showed that fiber content of coconut milk was 3.35%.

The determination of carbohydrate contents of creamed coconut and creamed coconut testa is highly important as carbohydrate is one of the macronutrients essential for human body. Not only they act as a source of energy, they also provide support for blood clotting, brain functioning, and growth of cells and tissues (deMan et al., 2018). According to data presented in Table 3, CC had a significantly ($p < 0.05$) higher carbohydrate content (9.12%) than CCT (7.89%). Nevertheless, there is a scarcity of literature data concerning the carbohydrate contents of creamed coconut testa. Appaiah et al. (2014) previously reported that the carbohydrate content of the whole copra, copra white kernel, copra testa, wet coconut whole, wet coconut white kernel, wet coconut testa were 24.30%, 22.40%, 26.30%, 12.30%, 10.60%, and 24.60%, respectively. Dendy & Timmins (1974) and Chakraborty (1985) previously reported that the carbohydrate content for mature coconut kernel as 9.9% and 16.9%, respectively. With regard to the composition of coconut milk, Belewu et al. (2014) reported that it had 14.30% of carbohydrate content. When examining CC, CCT and coconut milk, it's evident that coconut milk possesses a notably higher carbohydrate percentage.

Selection of the best creamed coconut testa dilution for potato curry

For culinary uses, the direct application of creamed coconut testa is not feasible and hence it can be reconstituted with an appropriate amount of warm water to make into either thick milk or thin milk. Identification of the correct dilution factor of creamed-paste for its use in potato curry is necessary. The data in Table 4 displays the sensory evaluation results of the Friedman test for the four different potato curry formulations. According to Table 4, significant ($p < 0.05$) differences were observed among the four formulations, regarding all sensorry attributes. In the ranking test, the lowest median is an indicator of the highest level of preference. According to Table 4, F1 had the highest preference rank level (lowest median) for appearance, aroma, colour and overall acceptability except for creaminess and flavor attributes. For creaminess and flavor, F2 formulation scored the highest preference level (lowest median). Furthermore, data showed that the preference of the panelists regarding appearance, aroma, colour and overall acceptability attributes seemed to declining with increasing level of CCT incorporation. However, the panelists' choice for the appearance, aroma, flavor, creaminess, and overall acceptability of F1 and F2 did not differ significantly ($p > 0.05$) except for colour. When compared to F3 and F4 formulation for creaminess, the flavor and overall acceptability did not differ significantly ($p > 0.05$) except for appearance, aroma and colour. F1, which was the potato curry prepared with 50 ml of creamed coconut testa with 450 ml of water formulation (CC:water = 1:9) was selected as the most preferred formulation based on all sensory attributes.

As shown in Figure 1, the radar chart illustrates the examination of the four formulations using the preference ranking test. The lowest median in a ranking test is a sign of the strongest level of preference. The maximum preference level is indicated by lines close to zero on the radar chart while the lines go away from zero indicate the gradually decreases in preference level. Based on Figure 1, it is observed that the lines denoting the medians pertaining to all sensory characteristics of the F4 formulation remained predominantly within the vicinity of near 4, with the exception of flavor and creaminess, where the median was noted near at 3. The entirety of sensory attributes within the F3 formulation were specifically localized to area 3. The median values

representing the flavor and creaminess of the F2 formulation have notably shifted toward the vicinity of 1, while other associated attributes lie within the range of 2. In contrast, the medians pertaining to sensory attributes of appearance, aroma, color, and overall acceptability in the F1 formulation have demonstrated a discernible movement closer to zero on the radar chart. Hence, F1 formulation which was prepared with 50 ml of creamed coconut testa with 450 ml of water (CC:water = 1:9) formulation was selected as the most preferred formulation.

Selection of the best creamed coconut dilution for potato curry

The sensory evaluation results of the Friedman test performed for different potato curry formulations, incoparated with creamed coconut are shown in Table 5. According to Table 5, significant ($p < 0.0001$) differences were noticed regarding all sensorry attributes. In terms of appearance, aroma, colour, P2 had the greatest preference rank level (lowest median) while P1 had the lowest preference rank level (highest median). For creaminess, flavor, and overall acceptability of both P2 and P3 formulations scored the highest preference level (lowest median). According to Table 5, there was no significant ($p > 0.05$) difference between P2 and P3 formulations for all attributes except for aroma. In evaluating aroma, findings indicate that formulations P1, P2, and P4 exhibited no notable ($p > 0.05$) variance. Considering all sensory attributes, P2 which was prepared with 100 ml of creamed coconut with 400 ml of water (CC: water = 1:4) formulation was selected as the most preferred formulations.

The radar chart in Figure 2 depicts the assessment of the four formulations through a preference ranking test. A lower median in the ranking test signifies a higher preference level. Lines nearing zero on the radar chart represent the highest preference level, while lines moving away from zero indicate a gradual decrease in preference level. All sensory qualities of the P1 formulation had median scores around 4, while the P4 formulation's median scores were around 3 for these attributes. All attributes of P3 and flavor, creaminess, and overall acceptability attributes of P2 formulation have exhibited near the value of 2. Moreover, appearance, aroma, and color of P2 formulation have shown the lowest median range. On the contrary, when examining the medians associated with sensory attributes of appearance, aroma, colour, creaminess, flavor, and overall acceptability in the P2 formulation, there is a noticeable shift towards zero on the radar chart. Hence, based on the graphical illustration, P2 sample which was prepared with 100 ml of creamed coconut with 400 ml of water (CC:water = 1:4) was selected as the most preferred formulation.

Benefits and advantages

Coconut cream and coconut milk both contain fat, protein, sugars, minerals, and vitamins as nutrients. The proportion of each nutrient might be different. Coconut milk is actually a fat in water emulsion but coconut cream products are viscous non-emulsion liquids. It is a well-known fact that the emulsion stability of coconut milk is a relatively low. Under ambient conditions, its emulsion may break down into two distinct phases: a heavy aqueous phase and a lighter creamy phase. This is not the case for the two coconut creamed products as they do not undergo phase separation immediately. The fat contents of coconut cream products are overwhelmingly high when compared to fresh coconut milk. Unlike the two coconut cream products, fat contents of coconut milk might vary depending on the volume of the water added to grated coconut during milk extraction. Owing to the high nutrients and moisture content, coconut milk is perishable and may undergo fast deterioration at room temperature condition. As the moisture content of the two creamed-paste is less than 0.85%, it may display a longer shelf-life stability at ambient temperature. Since they are prepared from the dehydrated coconut kernel or testa by grinding using an electrically-operated grinder, the temperature of the two-creamed products might rise above 80°C during the grinding process, which may help to pasteurize the substance inactivating microbes and enzyme activities. For culinary uses, the creamed-paste can be reconstituted readily with an appropriate amount of warm water to make into either thick milk or thin milk. In this way, we can reduce coconut wastage during the conventional method of coconut milk preparation.

Conclusion

The proximate compositions of creamed coconut and creamed coconut testa showed that there were significant variations in different component parameters exception for ash and moisture contents. The presence of low moisture content can be beneficial to the food quality and shelf-life stability of both products. The fat content, crude protein content, and carbohydrate content in creamed coconut was higher than those of creamed

coconut testa excluding crude fiber content. The ash content showed no significant difference between the two products, indicating that both products had the same amount of minerals. The sensory evaluation of the potato curry formulations which was incorporated with CCT, demonstrated that 50 ml of CCT and 450 ml of water (F1, CCT: water = 1:9) was the most preference formulation. In the case of creamed coconut formulations, 100 ml of CC with 400 ml of water (P2, CC:water = 1:4) was selected as the most preferred formulation based on sensory attributes. When evaluating the comparison of both products, CCT require a smaller quantity than CC for preparation of the best potato curry. Based on the results of this study, there is a potential use for coconut cream and coconut of creamed testa as a viable alternative for fresh coconut milk in culinary applications. Moreover, the outcome of this study suggests that the potential of commercializing these products due to the hectic lifestyles prevalent in these days, offering opportunities to save time and money while enhancing household well-being in Sri Lanka.

Acknowledgements

This study was partly funded by the National Institute of Fundamental Studies, Hanthana Road, Kandy, Sri Lanka.

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DOI: 10.37833/cord.v40i.446
Coconut Research & Development, 2024, 40, 41-48

Factors Influencing Coconut Growers' Decision-Making Process in Fertilizer Application through the Lens of Theory of Planned Behaviour and Self-Determination

C. S. Herath* and Rusitha Wijekoon

Technology Transfer Division, Coconut Research Institute of Sri Lanka, Lunuwila, 61150, Sri Lanka

* Corresponding author. Email: hmcsherath@yahoo.com

Abstract

The small-scale, poor, rural coconut growers in Sri Lanka are generally characterized by low productivity. The low yield of coconuts is primarily attributed to the improper application of fertilizers. The decision to apply fertilizer is mainly depends on the growers' change in behaviour, in turn, influenced by the growers' salient beliefs. Assessing the beliefs plays a significant role in understanding why farmers behave differently in making decisions regarding fertilizer application. The Theory of Planned Behaviour (TPB) and Theory of Self Determination (TSD) were employed to find a more realistic solution to the above research problem. Hence, the current research was carried out to observe the relationship between the beliefs of the coconut growers and their behaviour with respect to fertilizer application in coconut fields. Results of the study reveal that perceived behavioural control was the highest contributor to developing the intention followed by the attitude. Further, there is no influence from the social pressure for the intention development. Moreover, intrinsic motivation predicts the fertilizer application behaviour from intention in stronger strength than that of extrinsic motivation. Therefore, it can be concluded that motivation influences the intention-behavioural relationship. Consequently, it gives evidence for policymakers to introduce policy guidelines in order to enhance the use of fertilizer efficiently and effectively. And, motivation does have a moderating effect on coconut growers' fertilizer application behaviour.

Key words: Attitude, Extrinsic-motivation, Intention, Intrinsic-motivation, Perceived behavioural control, Sri Lanka

Introduction

The coconut growers especially the small-scale, poor, rural farmers in developing countries are generally characterized by low productivity. A major contributory factor for the low production is the acute soil degradation arising due to the use of non-sustainable farming practices (Herath, 2016). Sri Lankan small-scale coconut growers do not practice applying fertilizer to their coconut palms. Amongst plenty of reasons, the high price of fertilizer is one of the main contributors to the non-application of fertilizer (Herath, 2016). According to Herath's study, 14% of the coconut growers were aware of the adult palm mixture (APM), and 13% of the coconut growers were only aware of the young palm mixture (YPM). Moreover, it was found that 31% of the coconut growers never applied fertilizer to their coconut estates. Accordingly, it is obvious that most of the coconut growers were neither in the practice of applying fertilizer to their coconut farms though it

has been one of the quickest possible ways to increase the yield nor they were aware of the importance of applying fertilizer to their coconut lands.

The main factors that influence growers' fertilizer application behaviour vary according to their socio-economic conditions, beliefs, and attitudes, which may involve various decision stimuli (Herath, 2012). In turn, these stimuli vary according to the growers' beliefs, and attitudes. As a consequence, individual growers have their unique fertilizer application behaviour. In order to understand growers' actual behaviour of fertilizer application, it is necessary to explore how the growers' various decision stimuli give rise to a particular behaviour in fertilizer application. The present study aimed to identify factors that determine growers' fertilizer application, and examine the intention-behaviour relationship with respect to extrinsic and intrinsic motivations.

To evaluate growers' actual behavior regarding fertilizer application, various factors influence their decisions, including their goals, motives, emotions, government policies, and the availability of advisory services (Beedell & Rehman, 2000). The growers' decision variables and behaviour on fertilizer application could be explained well by the Theory of Planned Behaviour (TPB) (Ajzen, 2012). TPB helps to explain the growers' behaviour in terms of factors such as the growers' attitudes, social influences, and their ability to cope with problems encountered and opportunities available.

Literature Review

Theory of Planned Behaviour (TPB)

The theory of Reasoned Action (TRA) was initially developed by Ajzen and Fishbein in 1980 and suggested that human behaviour directly depends on a person's intention. In TRA, the intention is determined by two variables; attitudes, and subjective norms (SN). Later in 1991, Ajzen introduced an additional variable; perceived behavioural control (PBC) to increase the explanation power of the model, and developed a new theory; the TPB. In the theory, intention infers a person's readiness to accomplish a particular behaviour and is known as the motivation which is required for engagement in a given behaviour. The intention is the most significant predictor of the behaviour and is expected to be an immediate antecedent of that behaviour (Ajzen, 2002b). Moreover, to explain growers' decision-making process in the application of organic fertilizer, the TPB was 2 successfully used by Herath and Wijekoon in 2013 and 2021. A person's intention to accomplish a behaviour is a function of that person's attitude, SN, and PBC as presented in Figure 1 (Ajzen, 1991).

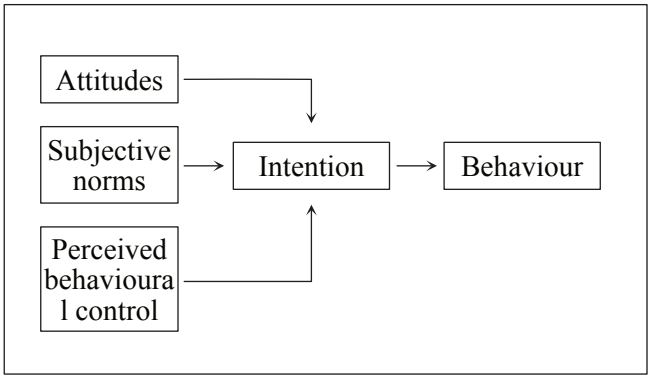

Figure 1. Diagram of Theory of Planned Behaviour (Ajzen, 1991)

Attitude is a person's positive or negative assessment of the performance of a specific behaviour (Ajzen & Fishbein, 1980). If an individual has a positive attitude towards a behaviour means that the individual trusts that important positive consequences would result from carrying out that behaviour. The attitude toward a behaviour is more favourable, and the possibility to perform a certain behaviour by an individual is very high (Ajzen, 2012). Further, several researchers found a significant positive association between growers' attitudes and intention or behaviour (Rezaei et al., 2019). Moreover, Savari & Gharechaee (2020) have emphasized the significance of attitude in predicting growers' fertilizer application behaviour.

A SN is an exerted social pressure on a person to perform a specific behaviour. People decide to implement a specific behaviour when they feel that the people who are important to them approve that behaviour (Ajzen & Fishbein, 1980). Results of previous studies where TPB was applied stated that the SN was the key factor affecting intention and behaviour (Arunrat et al., 2017). The same result was observed in the case of fertilizer application behaviours (Herath & Wijekoon, 2021; Savari & Gharechaee, 2020).

PBC could be defined as a person's perceived ease or difficulty of a specific behaviour performance. This factor highlights the degree to which a person perceives a behaviour to be under his/her volitional control (Ajzen & Fishbein, 1980). Behavioural control is related to beliefs about the presence of factors that may further or hinder the performance of behaviour (Ajzen, 2002b). Previous studies revealed the effect of PBC on intention (Mullan et al., 2013). Further, Savari & Gharechaee

(2020) applied the TPB in the context of agriculture to predict Iranian growers' intention for the safe use of chemical fertilizers, indicating that PBC was a significant factor affecting intention or behaviour.

The intention-behaviour gap was identified by (Ajzen, 2002a) who pointed out that the predictability of the model can be improved by incorporating other factors into the TPB, if they significantly contribute to the variance in intention or behaviour or intention-behaviour relationship (Ajzen, 2002b).

Self Determination Theory (SDT)

Self Determination Theory (SDT) is an empirically derived theory of human motivation and personality in social contexts that differentiates motivation in terms of being autonomous and controlled (Ryan & Deci, 2014). Examining the effects of extrinsic rewards on intrinsic motivation led to the development of the theory. Extrinsic-intrinsic classification is based on the degree to which motivation has been originated (Deci & Ryan, 2007). Perceived locus of causality (PLOC) is the key concept in SDT. The causes for a person's behaviour is measured by PLOC, and it ranges from externally to internally motivated behaviour (Deci & Ryan, 2007). Further, researchers used SDT and its mini-theories to guide and interpret research on many new issues, including motivation and wellness across cultures, close relationships, enhancement and depletion of energy and vitality, and the roles of both mindful awareness and non-conscious processes in behavioural regulation (Ryan & Deci, 2014). Several researchers have used the SDT for intrinsic and extrinsic motivation in several contexts to study their behaviour. Burton et al. (2006) examined Canadian students and revealed that intrinsic motivation was linked with psychological well-being, independent of academic performance. Tsai et al. (2008) evaluated German public school students' experiences of interest in three subjects. Therefore, SDT can be used as a supportive theory with TPB to assess the fertilizer application behaviour of the coconut growers in Sri Lanka.

Integrating a Moderator: Motivation

Motivation is the reason or reasons for one's behaviour. There are two types of motivations namely; intrinsic motivation (internal to the person), and extrinsic motivation (outside to the person). Intrinsic motivation refers to the behaviours done in the absence of external impetus that are inherently interesting and enjoyable (Miller et al., 1988). When individuals are motivated intrinsically, they engage, explore, and play in events for the integral challenge, excitement, and fun of doing so. Extrinsic motivation refers to the behaviours performed to obtain some outcome separable from the activity itself" (Miller et al., 1988). Moreover, SDT specifies four distinct types of extrinsic motivation that vary in the degree to which they are experienced as autonomous and that are differentially associated with classroom practices (e.g., autonomy-supportive versus controlling instruction) and learning outcomes (e.g., conceptual learning versus rote memorization) (Ryan & Deci, 2014). The previous studies on SDT suggested that both autonomous types of extrinsic motivation, and intrinsic motivation are favourable to engagement and explain the different behaviours, and perform as a moderating variable to explain the variance in the intention-behaviour gap. Chang & Wang (2011) applied motivation as a moderator to study the direct and indirect effects of retail environmental characteristics on impulse buying behaviour. Hence, the intrinsic and extrinsic motivation was integrated as a moderator to the conceptual framework.

To add new variables to the TPB framework, there are some requirements to be fulfilled (Ajzen, 2002a), thus, the causal relationship should be between the added variable and the behaviour. The motivations behind a behaviour and its origin are clearly explained in the SDT by Deci & Ryan (1985). This fulfils the Ajzen's first requirement, and therefore, motivation can be added as an additional moderator variable to the TPB.

According to the SDT, motivation is built upon three pillars; autonomy, and relatedness, competence, and is a unique concept. Autonomy represents a person's internal behaviour rather than external. Relatedness explains the relationships with society, and competence refers to the ability to do things successfully and effectively (Deci & Ryan, 2002). Further, the pillars in the motivation are as same as the variables in TPB. The SDT and the TPB explain the human psyche and fulfil the second requirement of Ajzen (1991), which is added variable should be a unique concept and suit the variables in the TPB.

Moreover, SDT basically differentiates four levels of motivation ranging from extrinsic to intrinsic motivation, and are measured by PLOC (Ryan & Deci, 2000). Ryan & Connell (1989) developed the Relative Autonomy Index which measures motivation and helps fulfil the third and fourth requirements of Ajzen (1991), pointing out that the added variable is exact, quantifiable and researchable.

The Conceptual Framework

TPB and SDT were combined to develop the conceptual framework. The integration of motivation into the TPB as a moderating variable will offer a more

complete view for the behavioural change. Motivation identifies factors that manipulate a person's behaviour, while TPB provides a framework to transfer beliefs into behaviour. Furthermore, adding motivation as a moderating variable to the standard TPB framework will enhance the intention-behaviour relationship. Likewise, it provides the answer to the behaviour of farmers towards fertilizer application decisions. Moreover, the theoretical framework of the study (Figure 2) was developed based on the above literature, and the hypotheses developed are;

H1: Growers' attitude has a positive significant effect on their intentions to apply fertilizer in coconut cultivation.
H2: Growers' SN has a positive significant effect on their intentions to apply fertilizer in coconut cultivation.
H3: Growers' PBC has a positive significant effect on their intentions to apply fertilizer in coconut cultivation.
H4: Growers' intrinsic motivation has a positive moderating effect on their fertilizer application intention-behaviour relationship.
H5: Growers' extrinsic motivation has a positive moderating effect on their fertilizer application intention-behaviour relationship.

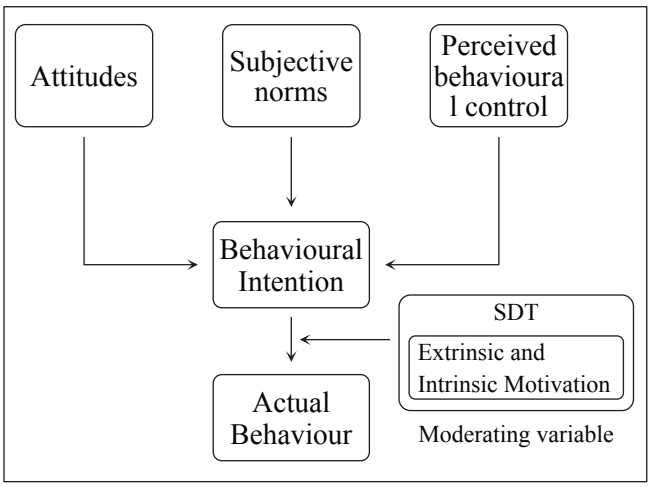

Figure 2. Integration of motivation into TPB model

Measuring Variables in Motivation

Connell and Ryan in 1989 developed the Relative Autonomy Index (RAI) to assess behaviour in academic-related work through motives. They identified four types of behavioural regulations namely; introjection regulation, external regulation, intrinsic motivation, and identification regulation. RAI respondents can be classified into Autonomous and Controlling groups (Ryan & Connell, 1989).

$$RAI = 2(Intrinsic) + 1(Identified) - 1(Introjected) - 2(External) \quad (1)$$

Measuring Variables in TPB

The expectancy-value method is widely used in behavioural studies to evaluate attitude. It quantifies, attitude by-product of belief and its evaluation. There are three basic elements in the expectancy-value method towards a behaviour to wit: belief (b), value (v) and attitude (a) (Viklund & Sjöberg, 2008).

$$a = \sum_{k=1}^{u} bivi \quad (2)$$

Based on the concept of TPB,

$$B \approx I \text{ œ } AT + SN + PBC \quad (3)$$

Where,
"B = Behaviour, I = Intention, AT = Attitude, SN = Subjective norm, PBC = Perceived behavioural control, bb = Behavioural belief, œ = Outcome evaluation, nb = Normative belief, mc= Motivation to comply, cb = Control beliefs, p = Power".

Therefore, a computable model of TPB can be given as;

$$B \approx I = \gamma_1 \sum_{i=1}^{s} bb_i oe_i + \gamma_2 \sum_{j=1}^{t} nb_j mc_j + \gamma_3 \sum_{k=1}^{u} cb_k p_k \quad (4)$$

Elicitation of the Salient Beliefs for TPB

Salient beliefs are developed in a person's mind when asked questions such as "What do you think would be the advantages for you to perform a certain behaviour?", and identified salient beliefs determine the respective attitude, SN, and PBC. The salient beliefs of a population could be identified by conducting an elicitation study (Gagné & Deci, 2005).

Materials and Methods

Identification of Salient Beliefs

According to Eccles et al. (2006), salient beliefs can be identified by conducting an elicitation study. An elicitation study was conducted in the coconut triangle (Kurunegala, Puttalum and Gampaha districts) of Sri Lanka with randomly selected 35 coconut growers in order to identify salient beliefs for the study.

Development of the Questionnaire

The questionnaire comprised of the recognized beliefs and indirect measures were used to assess the TPB variables; attitude, SN, and PBC. Further, variable attitude contained behavioural belief and outcome evaluation. The variable SN contained normative belief and motivation to comply. Finally, the control belief and power of control were the two components of PBC. Both had open-ended and close-ended questions. The close-ended questions were based on the 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5). Further, for the negative items, the reverse coding system was followed.

Sampling Method and Study Area

Dillman (2007) pointed out that to represent around 30,000 of the coconut growers in the coconut triangle, 365 respondents were sufficient, but 425 respondents will be targeted to compensate for incomplete/unresponsive questionnaires. Therefore, the data were collected from 175, 150, and 100 growers who were selected using stratified random sampling technique from Kurunegala, Puttalm, and Gampaha districts respectively to represent the coconut cultivation extent.

Data Collection

Field surveys were conducted in the coconut triangle of Sri Lanka which covered the main coconut growing areas, and comprises Kurunegala, Gampaha and Puttlam districts. Data collection was done through face-to-face interviews using a self-structured questionnaire with coconut growers. The effective response rate was 86.8%, 82.6%, and 90% with 152, 124 and 90 duly completed questionnaires returned, respectively. Finally, the total sample size was 366, and regression analysis was done using SPSS version 26.0.

Results and Discussion

Socio-Economic Characteristics of the Respondents

The summary of the socioeconomic characteristics of coconut growers in Gampaha, Kurunegala, and Puttlam districts is given in Table 1. The average age of growers in Gampaha, Kurunegala, and Puttlam districts were 59.5, 58.2, and 55.2 years, respectively. The majority of the growers were male. The coconut growers in Gampaha district have a higher educational background than Kurunegala, and Puttlam districts. With regard to the time involved in farming, the majority of growers in Gampaha, and Putlam districts were part-time growers, while majority of growers in Kurunegala were engaged in full-time farming. The average farm size of Puttlam district (17.4 ac.) was greater than Kurunegala (14.1 ac.), and Gampaha (4.3 ac.) districts.

Table 1. Socio-economic Characteristics of the Respondents

Characteristics	Gampaha	Kurunegala	Puttlam
Mean Age (Years)	59.5	58.2	55.2
Education (No. of years) (Mean)	12.2	12.0	11.2
Gender (M/F ratio) (Male)	90.40%	87.00%	80.69%
Involvement in farming			
Full time	23.84%	57.50%	28.58%
Part Time	76.16%	42.50%	71.42%
Farm size (ac) (Mean)	4.3	14.1	17.4

Reliability Analysis

The questionnaire was pre-tested to ensure validity and reliability. The Cronbach's alpha values for the questionnaire items were above 0.6, hence, values were within the acceptable range (Flury et al., 1988) with higher reliability.

Table 2. Reliability Analysis Results of the Variables

No.	Variable	Cronbach's alpha
1	Behavioural beliefs of fertilizer application	0.784
2	Normative beliefs of fertilizer application	0.856
3	Control beliefs of fertilizer application	0.711
4	Outcome evaluation	0.752
5	Motivation to comply	0.751
6	Power of control beliefs	0.672

Relationship between Intention and TPB Components

Table 3 explains the relationship of the attitude, SN, and PBC with the intention. Attitude and PBC explicate the intention significantly with positive relationships. The beta values are 0.29 ($p = 0.03$), and 0.37 ($p = 0.001$), respectively. The SN did not predict the intention ($p = 0.317$) implying that only attitude and PBC predict the intention to apply fertilizer while SN does not.

Table 3. Relationship of TPB Variables and Intention

TPB Variables	Dependent variable	Beta value	Significance
Attitude	Intension	0.29	0.03
Subjective Norm	Intension	0.12	0.317
Perceived Behavioural Control	Intension	0.37	0.001
R^2 value		42%	
F - statistics		15.18 (P < 0.003)	

The Link between Intention and Behaviour

The intention-behaviour relationship was assessed under intrinsic and extrinsic motivation separately. It was expected that when motivation is intrinsic, individuals are predicted to continue engaging in the behaviour and exhibit steady motivation. When the motivation is extrinsic, people are expected to keep engaging in the behaviour as long as the extrinsic motivation is in effect. When the motivated force is withdrawn, its effects cause changes in motivation resulting in changes the behaviour (Chatzisarantis & Biddle, 1998). If these considerations are held then motivation is expected to moderate the intention-behaviour relationship.

In order to test the moderating effect of motivation on the intention-behaviour relationship, RAI of the SDT was utilized to split the sample (366 respondents) into two groups namely: (a) controlled behavioural group (extrinsically motivated) with 274 respondents, and (b) autonomous behavioural group (intrinsically motivated) with 92 respondents. Four questions were asked to identify the motivation type of the farmers to measure (a) external regulation, (b) intrinsic motivation, (c) introjected regulation, and (d) identified regulation. Table 4 displays the mean value of the Likert scale of each type of motivation.

Table 4. Types of Motivation

Types of motivation	Mean Value in Likert Scale	Standard Deviation
External regulation	3.9	0.86
Introjected regulation	3.8	0.91
Identified regulation	2.7	0.76
Intrinsic motivation	2.1	0.84

The regression analysis was carried out separately to predict behaviour from intention under two forms of motivation. Table 5 shows that the coefficient (Beta value) of the intention-behaviour relationship differs across the groups. The model for intrinsic motivation was significant.

Table 5. The Relationship of Intension vs. the Behaviour

Independent variable	Dependent variable	Beta value (Intrinsic motivation)	Beta value (Extrinsic motivation)	Significance
Intension	Behaviour	0.68		0.000
R^2 value		43%		
F - statistics			23.43 (p <0.000)	
Intension	Behaviour		0.26	0.005
R^2 value			29%	
F - statistics			15.18 (p < 0.001)	

The attitudes showed a statistically significant contribution to explain the intention to apply fertilizer, and hence, hypothesis H1 was accepted. Further, attitude covers the beliefs that spontaneously come from their own feelings. Consequently, attitudinal appraisals are associated with intrinsic outcomes like satisfaction, enjoyment, interest, and self-improvement. Moreover, attitudinal appraisals are also associated with extrinsic outcomes like rewards and money. In the farming context, it is the desire for higher yield and profits. Therefore, farmers' intention to apply fertilizer is a result of attitudes they have held for a long time. Consequently, attitudes have a greater weight in explaining intention development. Results from previous studies by Bondori et al. (2018), Rezaei et al. (2019), and Savari & Gharechaee (2020) showed that the attitude had a significant association with the growers' intentions to apply agrochemicals.

Interestingly, there was no statistically significant association between SN and the intention to apply fertilizer. Therefore, the hypothesis H2 was rejected. When considering the cost of production in coconuts, the highest cost factor is the application of fertilizer. Though social pressure affects fertilizer application, growers make their own decisions. Furthermore, the result is in line with the study of Terano et al. (2015), indicating that SN had no significant association with the growers' intentions to apply fertilizer.

The PBC showed a statistically significant contribution to explain the intention to apply fertilizer with a strength of 0.37 (p = 0.001). It shows the highest strength to explain the intention, the PBC contributes greatly to developing intention for fertilizer application, hence, the hypothesis H3 was accepted. The present

finding was supported by the results of the studies conducted by Terano et al. (2015), Han (2015) and Savari & Gharechaee (2020).

When considering intrinsic motivation, the significant F value of 23.43 (p = 0.001), indicated that hypothesis H4 was accepted. The beta value explains the vigor of the intention and behaviour with a strength of 0.68 (p = 0.000). The model fit R2 value of 43% indicates the variance of the intrinsic motivation on the intention-behaviour relationship contributed to the coconut growers' fertilizer application decision-making process.

When considering the extrinsic motivation, the significant F value of 15.18 (p = 0.001), implied that hypothesis H5 was accepted. The intention-behaviour relationship had a coefficient of 0.26 (p = 0.000), which explains the vigor of the intention. The related R2 value of 29%, explained that only 29% of the variance of the extrinsic motivation on the intention-behaviour relationship contributed to the coconut growers' fertilizer application decision-making process.

Results showed that the types of motivation affect the predictive validity of intention. Further, both extrinsically motivated and intrinsically motivated individuals show a positive significant correlation between intention and behaviour. A significant quantity of evidence proved that both intrinsically and extrinsically motivated people engaged in positive behaviour (Chatzisarantis & Biddle, 1998).

However, there is a comparatively stronger link between intrinsic motivation than that of extrinsic motivation. The intrinsically motivated group has greater strength to express behaviour than the extrinsically motivated group indicating that intention is important in predicting behaviour regardless of type of the behavioural regulation. Though the internal regulation explains with greater strength, it is evident that motivation had a moderate effect on coconut growers' behaviour. The results of the study conform with the earlier findings of Kulik et al. in (2008) where there is a stable and stronger link for the intention-behaviour relationship for internally motivated groups than that of externally motivated groups. People keep on a certain behaviour should an activity makes them happy as a result of an intrinsic motivation. Further, the intrinsically motivated group behaved in a particular way because the motivation comes spontaneously from their own feelings which is an indication of a stable behaviour. The findings of this study are compatible with Miller et al. (1988) findings that behavioural regulations are more vital in determining behavioural adherence.

Conclusion

The study aimed to identify types of motivation and their impact on coconut growers' decision-making on fertilizer application. It also offers a more comprehensive understanding of motivation with respect to growers' beliefs, attitudes, intentions, and behaviours in fertilizer application. Moreover, two TPB variables such as attitude and PBC showed a positive significant relationship with the coconut growers' intention to apply fertilizer. The integration of the TPB and the SDT provides a more vigorous understanding of behavioural intention. Furthermore, the model with empirical support explained the correlation between intention and behaviour with different motivational types. It provides information about what factors to consider when determining the coconut growers' behaviour in fertilizer application. These findings provide groundwork for policymakers to provide improved support to coconut growers.

Acknowledgement

The authors are grateful to the National Research Council of Sri Lanka, (Grant No. NRC 13-59) for providing financial support for this study. Moreover, the authors are also thankful to the coconut growers for their valuable responses as respondents.

Conflict of Interest

The authors declare that there is no conflict of interest.

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