UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT AND EVALUATION OF TENERA OIL PALM PROGENIES DERIVED FROM SINGLE, DOUBLE AND THREE-WAY CROSSES

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IPTSM 2021 12

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By

KANDHA SRITHARAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

December 2020

DEDICATION

This thesis is dedicated to my family, friends, and mentor.

My father, Sritharan, for inspiring me to begin this journey. He has been my most trusted editor, reviewer, critique, and motivator. Thank you for your patience in reading this thesis eighteen million times and making corrections on every single draft. I would not have completed it without you.

My mother, Jayarani, for her endless love and support. Her affection, encouragement and prayers, day and night, has enabled me to achieve this success. As well as her constant nagging to complete my thesis so that she can finally tell people that we have a Doctor in the family.

My siblings, Jayaganesha and Gowri, for their unwavering support and encouragement. My brother has always been the creative and artistic one in the family whereas my sister is the most brilliant and naturally gifted. With this thesis, I can finally say that I am the best at something – being a nerd. My sister-in-law, Anushia, for her support and my niece, Danya, for being so cute.

My newly wedded wife, Natasha, for her constant love, support, encouragement, and patience. She sat in the car waiting while I made the presentation to upgrade my Masters to a PhD. She sat there under the hot sun and yet greeted me with the biggest smile as I came out about two and a half hours later. I will never forget that.

My friends, whose names shall not be spelled out (because I am bound to leave some out and suffer the wrath of it later), for their support, encouragement, and endless entertainment throughout my study period. This would have been a very dull journey with you guys.

My mentor, Dr Xaviar, for his professional guidance, knowledge, and encouragement. He told me to start my studies the day I started work. I started eight years later. I think he might still be displeased. But hey, it’s the destination that matters. Not the time you get there!

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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December 2020

Chairman : Professor Mohd Rafii bin Yusop, PhD
Institute : Tropical Agriculture and Food Security

Commercial oil palm plantings in Malaysia are primarily composed of single crosses. These crosses have limitations in their genetic potential, thus hindering efforts for further yield improvements. The primary objective of this study was to evaluate the yield potential, bunch characteristics and vegetative traits of oil palm progenies created from single (SC), three-way (TW) and double crosses (DC) and to assess their suitability for higher density planting. Thirty *Dura* x *Pisifera* (D × P) crosses were created using different parental lines to produce three samples of varying cross types, SC (10), TW (10) and DC (10) and planted in a randomized complete block design (RCBD) with three replicates (16 palms per replication). Except for a single round of vegetative measurements, palm yields and bunch characteristics were evaluated for a period of five years. All data were analysed using a Statistical Analysis Software (SAS ver. 9.4). The yield performance summarized by cross type showed significantly higher fresh fruit bunch (FFB) production in DC (210.42 kg per palm per year) compared to SC (187.00) and TW (196.94). The highest broad sense heritability estimates calculated decreases in the order: SC > TW > DC. There were no significant differences between the three cross types for all the bunch components analysed except for mean weight per fruit (MWF); approximately 17% higher in both TW and DC compared to SC. Estimated fresh fruit bunch yields per hectare (FFBHa) was 12.5 and 6.8% higher in DC compared to SC and TW, respectively. Oil yield per hectare (OHa) and oil yield per palm (OYP) for DC was 17.6 and 10.7% higher than SC and TW, respectively. There were no significant differences between cross types for any of the vegetative traits quantified in this study. For the same parameters, within crop types, DC showed the most significant differences between progenies indicating the highest segregation of vegetative traits. Progenies DC2, SC8, DC9, TW7, TW2, SC1, SC3 and DC1 with short fronds showed the greatest potential for higher density planting. The DC2 with the shortest fronds planted at a density of 201 palms per hectare is estimated to yield 10.66 t ha^{-1} oil annually. Strong significant positive correlations existed between OYP/OHa and average bunch weight (BWT), mesocarp to bunch ratio (MB), oil to bunch ratio (OB) and FFBHa. There was no significant correlations observed between any of the vegetative traits with yield or bunch components. Path coefficient analysis carried out showed contrasting results between SC and both TW and DC. In all three cross types however, fruit to bunch ratio (FB) and MB possessed the greatest influence over OHa both as a direct effect and indirect effect through other traits. Creation of multiway crosses did improve yield potentials with DC showing a clear advantage over the others. The creation of multiway crosses is therefore a vital step in breeding leading to higher segregation enabling the selection of an array of traits useful in the endeavours to improve commercial yields nationwide.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGHASILAN DAN PENILAIAN PROGENI KELAPA SAWIT TENERA BERASAL DARIPADA KACUKAN SATU, DUA DAN TIGA HALA

Oleh

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Pengerusi : Profesor Mohd Rafii bin Yusop, PhD
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Penanaman kelapa sawit komersial di Malaysia terdiri terutamanya daripada salib satu hala. Salib ini mempunyai batasan dalam potensi genetik mereka yang menghalang usaha untuk penambahbaikan hasil selanjutnya. Objektif utama kajian ini adalah untuk menilai potensi hasil, ciri-ciri tandan dan ciri-ciri vegetatif progeni kelapa sawit yang dicipta daripada satu hala (SC), tiga hala (TW) dan dua hala (DC) dan untuk menilai kesesuaian mereka untuk penanaman ketumpatan yang lebih tinggi. Tiga puluh salib *Dura x Pisifera* (D × P) dicipta menggunakan ibu bapa yang berbeza untuk menghasilkan tiga sampel salib yang berlainan jenis, SC (10), TW (10) dan DC (10), dan ditanam dalam reka bentuk blok lengkap rawak (RCBD) dengan tiga replika (16 pokok sawit setiap replikasi). Kecuali pengukuran vegetative yang dilakulan pada akhir tempoh, hasil sawit dan ciri-ciri tandan telah dinilai untuk tempoh lima tahun. Semua data dianalisis menggunakan Statistical Analysis Software (SAS ver.9.4). Prestasi hasil yang dirumuskan mengikuti jenis salib menunjukkan pengeluaran Tandan Buah Segar (FFB) yang lebih tinggi dalam DC (210.42 kg setiap pokok sawit setahun) berbanding SC (187.00) dan TW (196.94). Nilai keterwarisan secara luas yang dikira berkurangan dalam perintah itu: SC > TW > DC. Tiada perbezaan ketara antara ketiga-tiga jenis salib untuk semua komponen tandan yang dianalisasikan kecuali berat min bagi setiap buah (MWF) iaitu kira-kira 17% lebih tinggi dalam kedua-dua TW dan DC berbanding SC. Anggaran hasil tandan buah segar sehektar (FFBHa) adalah 12.5 dan 6.8% lebih tinggi dalam DC berbanding SC dan TW, manakala hasil minyak sehektar (OHa) dan hasil minyak setiap sawit (OYP) bagi DC adalah 17.6 dan 10.7% lebih tinggi daripada SC dan TW masing-masing. Tiada perbezaan yang ketara antara jenis salib untuk mana-mana ciri-ciri vegetatif yang dikuantitikan dalam kajian ini. Untuk ciri-ciri yang same, dalam setiap jenis salib, DC memiliki perbezaan yang paling ketara antara progeny yang menunjukkan segregasi yang paling banyak. Progeni DC2, SC8, DC9, TW7, TW2, SC1, SC3 dan DC1 dengan pelepah pendek menunjukkan potensi terbesar untuk penanaman ketumpatan yang lebih tinggi. Jika ditanam pada kepadatan 201 pokok sehektar, DC2 dengan pelepah terpendek dianggarkan menghasilkan 10.66t ha^{-1} minyak setiap tahun. Korelasi positif yang ketara dilihat antara OYP/OHa dan purata berat tandan (BWT), mesocarp kepada nisbah tandan (MB), nisbah minyak kepada tandan (OB) dan FFBHa. Tiada korelasi dilihat antara mana-mana ciri-ciri sayur-sayuan dengan hasil atau komponen tandan. Analisis pekali laluan yang dijalankan menunjukkan keputusan yang berbeza antara SC dan kedua-dua TW dan DC. Walaubagaimanapun, dalam ketiga-tiga jenis salib, nisbah buah kepada tandan (FB) dan MB memiliki pengaruh terbesar ke atas OHa sebagai kesan langsung dan tidak langsung melalui ciri-ciri lain. Dari kajian ini jelas bahawa penciptaan salib pelbagai hala telah meningkatkan potensi hasil. DC menunjukkan kelebihan yang jelas berbanding SC dan. Oleh itu, penciptaan salib pelbagai hala adalah langkah penting dalam pembiakbakaan yang membawa kepada pengasingan yang lebih tinggi membolehkan pemilihan pelbagai sifat berguna dalam usaha untuk meningkatkan hasil komersial di seluruh negara.

ACKNOWLEDGEMENTS

First and foremost, my utmost appreciation to Universiti Putra Malaysia and its administration for their professionalism, guidance, and opportunity to further my education. Also, to the qualified and dedicated professionals who guided me along my PhD Journey.

My deepest gratitude to the Chairman of my supervisory committee, Professor Rafii Yusop, for his vital inputs and guidance throughout this research. His knowledge, professionalism, kindness, and patience has been invaluable. It was a great privilege and honour to study under his guidance.

To the supervisory committee members, Professor Yusoff bin Abd Samad, Dr Mashitah Jusoh and Dr Xaviar Arulandoo, my sincerest appreciation for all the assistance, advice and time given in ensuring the success of this study. A special thanks is given to Puan Norhasimah from ITAFoS. She has been instrumental in my journey as a student. Her kindness, helpfulness and dedication are truly admirable.

My gratitude also goes to United Plantations Berhad for making me the man I am today. Thank you for fostering my career as a breeder in oil palm and coconuts and providing me with all the tools and resources necessary to complete this study. Dato Carl Bek Nielsen, the Chief Executive Director, has been a role model throughout my career with his exemplary leadership, dedication, perseverance, intelligence, and professionalism. His approval and support in my higher education is deeply appreciated.

Last but not the least, I am indebted to my family, whose value to me only grows with age. Their inspiration, encouragement, guidance, and love are the primary reason I began, struggled through, and completed this long journey. Words can not describe the gratitude I have for them.

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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This is to confirm that:

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LIST OF ABBREVIATIONS

ABW	Average Bunch Weight
ANOVA	Analysis of Variance
B	Borate
BNO	Bunch Number
CBP	Combined Breeding Programme
cm	Centimeter
CPO	Crude Palm Oil
CV%	Coefficient of Variance
D	*Dura*
D × P	*Dura* × *Pisifera*
d.f.	Degree of Freedom
DC	Double Cross
DOA	Department of Agriculture
D_{opt}	Optimal Density
F1	First Generation
F2	Second Generation
FB	Fruit to Bunch Ratio
FC	Fruit Composition
FELDA	Federal Land Development Authority
FFB	Fresh Fruit Bunch
FFBHa	Fresh Fruit Bunch Yields per Hectare
FrL	Frond Length
g	Grams
GCA	General Combining Ability
GCV	Genotypic Coefficient of Variance
GDP	Gross Domestic Product
GV	Genotypic Variance
h2	Broad Sense Heritability
HSD	Honestly Significant Difference

ID	Identity
INEAC	Institut National pour l'Etude Agronomique du Congo belge
IRHO	Institut de Recherches pour les Huiles et Oléagineux
KB	Kernel to Bunch Ratio
kg	Kilograms
kg p^{-1}	Kilograms per palm
Ks	Kieserite
LAI	Leaf Area Index
LAP	Leaf Area per Palm
LSD	Least Significant Difference
MB	Mesocarp to Bunch Ratio
MF	Mesocarp to Fruit Ratio
mm	Millimeter
MOP	Muriate of Potash
MPD	Maximum Potential Density
MPOB	Malaysian Palm Oil Board
MRS	Modified Recurrent Selection
MWF	Mean Weight per Fruit
N	Number of palms/plots sampled
OB	Oil to Bunch Ratio
ODM	Oil to Dry Mesocarp Ratio
OER	Oil Extraction Rate
OHa	Oil Yields per Hectare
OPGL	Oil Palm Genetics Laboratory
OWM	Oil to Wet Mesocarp Ratio
OYP	Oil Yields per Palm
P	*Pisifera*
PCV	Phenotypic Coefficient of Variance
PHt	Palm Height
PKC	Palm Kernel Cake
PKO	Palm Kernel Oil

PV	Phenotypic Variance
RCBD	Randomized Complete Bock Design
RDS	Raw Data Sheet
RFLP	Restriction Fragment Length Polymorphism
RM	Ringgit Malaysia
RP	Rock Phosphate
RRS	Reciprocal Recurrent Selection
SE	Standard Error
SAS	Statistical Analysis Software
SB	Shell to Bunch Ratio
SBP	Sabah Breeding Programme
SC	Single Cross
SCA	Specific Combining Ability
SIRIM	Standard and Industrial Research Institute of Malaysia
Std Error	Standard Error
T	*Tenera*
$t\ ha^{-1}$	tonnes per hectare
TD	Trunk Diameter
TSWV	Tomato Spotted Wilt Virus
TW	Two-Way Cross
TYLCV	Tomato Yellow Leaf Curl Virus
UPB	United Plantations Berhad
VD	Variable Density

CHAPTER 1

INTRODUCTION

The Malaysian oil palm industry had in 2019 contributed RM64.84 billion to the Gross Domestic Product (GDP) accounting for approximately 29% of the world palm oil production (MPOB Statistics, 2020). The oil palm is believed to have been first introduced in Malaysia in the early 1900s, owing primarily to optimal environmental conditions (tropical climate), suitable soil and absence of pests and diseases commonly found in Africa. The oil palm thrived in Malaysia and it was only in the 1960s that oil palm as a crop found stability. The impetus came with the decline in the price of rubber and the government's effort to bridge income gaps in the rural areas. The government established the Federal Land Development Authority (FELDA) tasked with the challenge of providing land for the landless and jobs for the jobless (NST, 2017). The land area in hectares planted with oil palm grew from 5500 in 1960 to a total of 5.90 million by the end of 2019 (MPOB Statistics, 2020). Production of palm oil increased from less than 100,000 tonnes in 1960 to approximately 19.86 million tonnes in 2019 (MPOB Statistics, 2020). About 90% of the annual production is exported to over 200 countries worldwide making up approximately 37% of the world exports (MPOB Statistics, 2020).

Despite the incredible progress and contributions, the oil palm industry has made in recent years, the industry is plagued with an array of issues. These challenges might significantly hinder the future development and expansion of oil palm in Malaysia. The external factors that could affect the industry are other alternative vegetable oils, concerns of deforestation, availability of labour and immigration policies. Those involved in the research and development and cultivation have little control over these issues. Their primary concern is stagnating yields. The estimated yield in 2019 averaged across mature plantings in Malaysia is 3.42 tonnes of crude palm oil (CPO) per hectare. From 1990 to present, the yield per hectare has been fluctuating around 3.6 tonnes CPO per hectare annually (MPOB Statistics, 2020). Low quality planting materials coupled with sub-standard agronomic practices are amongst the factors contributing to stagnating national yields. Currently, it has been estimated that oil palm is planted in almost 58% of Malaysia's total agricultural land (10.49 million hectares) leading to a constraint in new arable land available for oil palm (Nambiappan et al., 2018).

To increase oil palm yields, the focus should shift from individual palm yield to yield per given land area. In this respect, planting density can be exploited to improve yields. Efforts are needed to shift from the low density (120-148 palms per hectare) to high density of 150-180 palms per hectare (Latif et al., 2003). This could increase yields per hectare by 20 to 25%.

The primary objective of oil palm breeding programmes is the creation of planting materials with a high yield potential. The germplasm material known as Deli *dura* was the first generation of commercial plantings in Malaysia (Rajanaidu et al., 1979). In 1941, the discovery of the single gene inheritance for shell thickness revolutionized the oil palm industry worldwide. Thinner shell or endocarp meant thicker mesocarp, the oil-bearing pulp, and hence higher yield potentials (Sambanthamurthi et al., 2009). In 1953, the Department of Agriculture (DOA) began with commercial plantings of *dura* by *pisifera* hybrids, better known as D×P hybrids. By 1959, the entire oil palm industry in Malaysia quickly followed DOA's footsteps and switched to D×P planting materials (Kushairi et al., 1999).

The parent germplasm used by most agencies in Malaysia has not changed much in the past few decades. Breeding programmes focused on selfing and inbreeding to carry forward the same genetic stock to the next generation. This led to increased homozygosity and reduced variability. Due to this, there is at present increasing pressure to create new materials with higher variability and genetic potential for breeding and selection. Materials capable of high-density planting has been a goal for breeders. Long term density trials with currently available *tenera* materials showed that at a higher density of 183 palms per hectare fresh fruit bunch (FFB), bunch number (BNO) and average bunch weight (ABW) was reduced (Ramachandran et al., 1973). There is a need to create palms with smaller vegetative growth characteristics, such as short fronts and height while maintaining the individual palm yield.

Cross-fertilization had frequently resulted in increased size, vigour and productivity of offspring compared to self-fertilization (Stuber, 1994). These improved traits seen in the progeny is called heterosis or hybrid vigour. Hybrid breeding to capitalize on heterosis was first introduced in the United States in the early 20th century. Since then, maize yields have increased five-fold and rice varieties have gained 11.3% in grain yields (Prohens, 2011; Jiang et al., 2016). Hybrid crop breeding strategies was adopted by oil palm breeders with the biggest and most significant breakthrough being the creation of *tenera* crosses to produce superior planting materials. '

Creation of multi-way crosses is a technique that can be used in the oil palm industry to increase heterosis. Heterosis is usually at its highest when both parental lines have the most genetic distance with different but complimentary traits. As such, creating more diverse parents through the introgression of multiple germplasms or breeding lines should theoretically increase the level of heterosis especially if individual parents with complimentary traits are selected and crossed (UPB Internal Report, 2015). In oil palm breeding, the highly homozygous Deli *dura* is the perfect maternal parent with its large average bunch weight, high receptivity to hybridization and good seed yield per cross. The paternal parent, the *pisifera*, on the other hand comes in many varieties with the commonly used germplasms being AVROS, Yangambi, Yocoboue and JenTT. These germplasms have been maintained as pure lines maintaining its homozygosity through successive inbreeding and have to a certain extend reached its maximum genetic potential for yield when combined with the Deli *dura* (UPB External Consultant Report, 2019). Introgression of these lines, such as JenTT/Yocoboue or JenTT/Yocoboue//Yangambi to create new paternal parental lines could bring together complimentary traits and increases the genetic distance between parents. These three-way and double crosses with the Deli *dura* form the basis of multi-way crosses.

1.1 Problem Statement

The primary concern for researchers and cultivators of oil palm is the stagnating yield. Among the factors for stagnating yield is the planting materials used. Present germplasms used by most agencies in Malaysia has not changed much in the past few decades and may have reached their cap in terms of yield potential. As such, there is increasing pressure to create new materials with higher variability and genetic potential. Faced with limited germplasm and difficulties in importing newer breeding materials, breeders are left with no other choice but to move away from single crosses and begin forming three-way and double crosses. These crosses, however, have not been tested to determine the theoretical yield potential to further improve commercial yields. Besides that, it is also believed that the introgression of multiple breeding lines would lead to higher segregation and as such create more variability. This variability could theoretically be exploited to create progenies with improved vegetative traits capable of higher density planting.

1.2 Research Objectives

The main objective of the research was to develop oil palm *tenera* planting materials with high FFB and oil yields capable of planting at a higher density to maximize returns on a given area of land. The specific objectives were: -

i. To quantify and evaluate the yield, bunch components and vegetative traits amongst single, three-way and double crosses.

ii. To estimate heritability values for each trait of the oil palm population.

iii. To estimate the gain in yield (if any) obtained through increasing heterosis and estimate the commercial yield potential obtainable through conventional breeding.

iv. To select for progenies with improved vegetative traits (such as shorter trunks, smaller fronds and thicker canopy) and high individual palm yields suitable for higher density planting.

v. To investigate correlations and path coefficients amongst all these quantified traits (yield, bunch and vegetative) to facilitate future selections.

BIBLIOGRAPHY

Shuib, A. R., Khalid, M. R., & Deraman, M. S. (2010). Enhancing field mechanization in oil palm management. *Oil Palm Bulletin*, *61*(November), 1–10. Retrieved from http://palmoilis.mpob.gov.my/publications/OPB/opb61-Rahim.pdf.

Adam, H., Collin, M., Richaud, F., Beulé, T., Cros, D., Omoré, A., Nodichao, L., Nouy, B., Tregear, J. W. (2011, December). Environmental regulation of sex determination in oil palm: Current knowledge and insights from other species. *Annals of Botany*. https://doi.org/10.1093/aob/mcr151.

Alam, A. F., Er, A. C., & Begum, H. (2015). Malaysian oil palm industry: Prospect and problem. *Journal of Food, Agriculture & Environment*, 13(2), 143-148.

Aliyu, A. S., Aziz, A. A., Yahya, A., & Lattiff, Z. A. (2015). Potential of oil palm frond liquid extract and fiber as feedstock for bio-butanol production. *Jurnal Teknologi*, *74*(10), 63–67. https://doi.org/10.11113/jt.v74.4835.

Allard, R. W. (1960). Selection under self-fertilization. *Principles of Plant Breeding, John Wiley & Sons, Inc*, 55.

Almasy, L., & Blangero, J. (2010). Variance component methods for analysis of complex phenotypes. *Cold Spring Harbor Protocols*, *5*(5). https://doi.org/10.1101/pdb.top77

Arias, D., González, M., Prada, F., Ayala-Diaz, I., Montoya, C., Daza, E., & Romero, H. M. (2015). Genetic and phenotypic diversity of natural American oil palm (*Elaeis oleifera* (HBK) Cortés) accessions. *Tree Genetics & Genomes*, *11*(6), 1-13.

Arulandoo, X., Sritharan, K., & Subramaniam, M. (2015). Performance of coconut hybrids in United Plantations Berhad and commercial production of seed nuts. *CORD*, 2015(2). https://doi.org/10.37833/cord.v30i2.78

Ataga, C. D. (1995). Character interrelationships and path coefficient analysis for oil yield in the oil palm. *Annals of Applied Biology*, 127(1), 157-162. https://doi.org/10.1111/j.1744-7348.1995.tb06660.x

Ballou, J. D. (1983). Calculating inbreeding coefficients from pedigrees. *Genetics and Conservation: A Reference for Managing Wild Animal and Plant Populations*, 509-520.

Beirnaert, A. D. F., & Vanderweyen, R. (1941). Contribution à l'étude génétique et biométrique des variétés *d'Elaeis guineensis* Jacquin. *East African Standard*.

Benesty, J., Chen, J., Huang, Y., & Cohen, I. (2009). Pearson correlation coefficient in noise reduction in speech processing. *Springer*, 1-17.

Birchler, J. A., Yao, H., Chudalayandi, S., Vaiman, D., & Veitia, R. A. (2010). Heterosis. *The Plant Cell*, 22(7), 2105-2112. https://doi.org/10.1105/tpc.110.076133

Blaak, G., Sparnaaij, L. D., & Menedez, T. (1963). Breeding and inheritance in the oil palm (*Elaeis guineensis* Jacq.) II. Methods of bunch quality analysis. *Journal of West African Institute for Oil Palm Research*, 4(14), 146-155.

Bondari, K. (1990). Path analysis in agricultural research. *Conference on Applied Statistics in Agriculture*. Retrieved from https://doi.org/10.4148/2475-7772.1439.

Bonneau, X., Vandessel, P., Buabeng, M., & Erhahuyi, C. (2014). Early impact of oil palm planting density on vegetative and oil yield variables in West Africa. *Oilseeds and Fats, Crops and Lipids*, 21(4). https://doi.org/10.1051/ocl/2014009.

Bonneau, X., Impens, R., & Buabeng, M. (2018). Optimum oil palm planting density in West Africa. *Oilseeds and Fats, Crops and Lipids*, 25(2). https://doi.org/10.1051/ocl/2017060

Breure, C. J. (2010). Rate of leaf expansion: A criterion for identifying oil palm (*Elaeis guineensis* Jacq.) types suitable for planting at high densities. *NJAS-Wageningen Journal of Life Sciences*, 57(2), 141-147. https://doi.org/10.1016/j.njas.2010.03.001

Breure, C. J., & Bos, I. (1992, January). Development of elite families in oil palm (Elaeis guineensis Jacq.). *Euphytica*. Kluwer Academic Publishers. https://doi.org/10.1007/BF00023543

Burton, G. W., & DeVane, E. H. (1953). Estimating heritability in tall fescue (Festuca Arundinacea) from replicated clonal material 1. *Agronomy Journal*, *45*(10), 478–481. https://doi.org/10.2134/agronj1953.00021962004500100005x

Chan, K. S., Soh, a C., & Chew, P. S. (1999). An accurate and precise method of determining oil to bunch in oil palm. *Oil Palm Research*, *11*(1), 11–22. Retrieved from palmoilis.mpob.gov.my/publications/joprv11n1-p2.pdf

Chun, T. C., Ling, C. K., Hee, L. C., Choo, C. S., Barin, J., Fong, A. W., Guan, T. S. (2018). Genetic diversity and inbreeding level in deli dura and avros advanced breeding materials in oil palm (elaeis guineensis jacq.) using microsatellite markers. *Journal of Oil Palm Research*, *30*(3), 366–379. https://doi.org/10.21894/jopr.2018.0044

Cochard, B., Amblard, P., & Durand-Gasselin, T. (2005). Oil palm genetic improvement and sustainable development. *OCL - Oleagineux Corps Gras Lipides*. John Libbey Eurotext. https://doi.org/10.1051/ocl.2005.0141

Cohen, P., Cohen, P., West, S. G., & Aiken, L. S. (2014). *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences*. Psychology Press. London.

Corley, R. H. V. (1973). Effects of plant density on growth and yield of oil palm. *Experimental Agriculture*, *9*(2), 169–180. https://doi.org/10.1017/S0014479700005639

Corley, R. H. V. (1976). Plant density - Oil palm research. *Elsevier*. 273–283.

Corley, R. H. V. (2018). Studies of bunch analysis 2-bunch sampling to estimate oil yield. *Journal of Oil Palm Research*, 30(2), 206-218. https://doi.org/10.21894/jopr.2018.0019

Corley, R. H. V., & Gray, B. S. (1976). Growth and morphology: Development in crop science, *Oil Palm Research*.

Corley, R. H. V., & Tinker, P. B. (2008). *The oil palm.* John Wiley & Sons, United Kingdom.

Corley, R. H. V., & Tinker, P. H. B. (2016). *The oil palm, 5th edition*. Wiley Blackwell, United Kingdom.

Cronquist, A., & Takhtadzhian, A. L. (1981). An integrated system of classification of flowering plants. *Columbia University Press*.

Cros, D., Sánchez, L., Cochard, B., Samper, P., Denis, M., Bouvet, J. M., & Fernández, J. (2014). Estimation of genealogical coancestry in plant species using a pedigree reconstruction algorithm and application to an oil palm breeding population. *Theoretical and Applied Genetics*, 127(4), 981-994. https://doi.org/10.1007/s00122-014-2273-3

Crow, J. F. (2001). Heterosis. *Encyclopedia of Genetics.* Elsevier Science Incorporated, Amsterdam.

de Almeida Rios, S., da Cunha, R. N. V., Lopes, R., Barcelos, E., da Rocha, R. N. C., & de Lima, W. A. A. (2018). Correlation and path analysis for yield components in dura oil palm germplasm. *Industrial Crops and Products*, 112, 724-733. https://doi.org/10.1016/j.indcrop.2017.12.054

Deshmukh, S. N., Basu, M. S., & Reddy, P. S. (1986). Genetic variability, character association and path coefficients of quantitative traits in Virginia bunch varieties of groundnut. *Indian Journal of Agricultural Sciences*.

Dransfield, J., Uhl, N. W., Asmussen, C. B., Baker, W. J., Harley, M. M., & Lewis, C. E. (2005). A new phylogenetic classification of the palm family, *Arecaceae*. *Kew Bulletin*, 559-569. https://doi.org/10.2307/25070242

Dudley, J. W., & Moll, R. H. (1969). Interpretation and use of estimates of heritability and genetic variances in plant breeding. *Crop Science*, 9(3), 257-262.

Escobar, R., Sterling, F., & Peralta, F. (1996). Oil Palm Planting Materials by ASD de Costa Rica. *ASD Oil Palm Papers*, *14*(14), 1–12.

Falconer, D. S. (1960). *Introduction to Quantitative Genetics*. Pearson Education, India.

Field, A. (2013). Everything you never wanted to know about statistics. *Discovering Statistics Using IBM SPSS Statistics*. SAGE, London.

Fry, J. (2009). The Challenges Facing Palm Oil in the 21st Century. *PAC Seminar Proceedings, MPOB*.

Gerritsma, W., & Soebagyo, F. X. (1999). An analysis of the growth of leaf area of oil palms in Indonesia. *Experimental Agriculture*, 35(3), 293-308. https://doi.org/10.1017/S0014479799003038

Goh, K. J. (1977). Fertilizer recommendation systems for oil palm: Estimating the fertilizer rates. *Proceedings of MOSTA Best Practices Workshops: Agronomy and Crop Management, Malaysia, March to August 2004. Sdn*, 235–268. Retrieved from http://www.aarsb.com.my/AgroMgmt/OilPalm/FertMgmt/Computation/Fertilizer recommendation systems for oil palm - estimating the fertilizer rates.pdf

Griliches, Z. (1960). Hybrid corn and the economics of innovation. *Science*, 132(3422), 275-280. https://doi.org/10.1126/science.132.3422.275

Hallauer, A. R. (1999). Temperate maize and heterosis. *Genetics and Exploitation of Heterosis in Crops*, American Society of Agronomy, Wisconsin.

Hardon, J. J., Williams, C. N., & Watson, I. (1969). Leaf area and yield in the oil palm in Malaya. *Experimental Agriculture*, *5*(1), 25-32. https://doi.org/10.1017/S0014479700009935

Hardon, J. J., Corley, R. H. V., & Ool, S. C. (1972). Analysis of growth in the oil palm II. Estimation of genetic variances of growth parameters and yield of fruit bunches. *Euphytica*, *21*(2), 257–264. https://doi.org/10.1007/BF00036765

Hardon, J. J., Rao, V., & Rajanaidu, N. (1985). A review of oil-palm breeding. *Progress in Plant Breeding-1*, Elsevier, Amsterdam.

Hardwick, S. R., Toumi, R., Pfeifer, M., Turner, E. C., Nilus, R., & Ewers, R. M. (2015). The relationship between leaf area index and microclimate in tropical forest and oil palm plantation: Forest disturbance drives changes in microclimate. *Agricultural and Forest Meteorology*, *201*, 187-195. https://doi.org/10.1016/j.agrformet.2014.11.010

Hartley, C. W. S. (1967). *The Oil Palm*. Longman, London.

Hartley, C.W.S. (1988). *The Oil Palm. Third Edition*. Longman, London.

Harun, M. H., & Noor, M. R. M. (2002). Fruit set and oil palm bunch components. *Journal of Oil Palm Research*, 14(2), 24-33.

Henson, I. E. (2003). The Malaysian national average oil palm: Concept and evaluation. *Oil Palm Bulletin*, *46*(May), 15–27. Retrieved from http://palmoilis.mpob.gov.my/publications/OPB/opb46-IanHenson.pdf

Henson, I. E., & Dolmat, M. T. (2003). Physiological analysis of an oil palm density trial on a peat soil. *Journal of Oil Palm Research*, 15(2).

ICS (2019). Hybrid Tomatoes for agriculture Africa. Retrieved from https://www.ics-agri.com/tomatoes-hybrids-seeds-semadonis.html.

Jiang, P., Xie, X., Huang, M., Zhou, X., Zhang, R., Chen, J., Wu, D., Xia, B., Xiong, H., Xu, F. & Zou, Y. (2016). Potential yield increase of hybrid rice at five locations in southern China. *Rice*, 9(1), 11. https://doi.org/10.1186/s12284-016-0085-6

Johari, A., Nyakuma, B. B., Nor, S. H. M., Mat, R., Hashim, H., Ahmad, A., Zakaria, Z.Y. & Abdullah, T. A. T. (2015). The challenges and prospects of palm oil based biodiesel in Malaysia. *Energy*, 81, 255-261. https://doi.org/10.1016/j.energy.2014.12.037

Johnson, H. W., Robinson, H. F., & Comstock, R. (1955). Estimates of genetic and environmental variability in soybeans 1. *Agronomy Journal*, 47(7), 314-318. https://doi.org/10.2134/agronj1955.00021962004700070009x

Joshi, P. (2018). Path Coefficient Analysis | Biostatistics. Retrieved from http://www.biologydiscussion.com/biostatistics-2/path-coefficient-analysis-biostatistics/47329.

Junaidah, J., Rafii, M. Y., Chin, C. W., & Saleh, G. (2011). Performance of tenera oil palm population derived from crosses between deli dura and pisifera from different sources on inland soils. *Journal of Oil Palm Research*, 23, 1210-1221.

Kiple, K. F., & Ornelas, K. C. (2000). Palm Oil. *The Cambridge World History of Food.* Cambridge University Press, United Kingdom.

Krualee, S., Sdoodee, S., Eksomtramage, T., & Sereeprasert, V. (2013). Correlation and path analysis of palm oil yield components in oil palm (*Elaeis guineensis* Jacq). *Kasetsart Journal (National Science)*, 47, 528-533.

Kushairi, A. and Rajanaidu, N. (2000) Breeding populations, seed production and nursery management. *Advances in Oil Palm Research*, Malaysian Palm Oil Board, Malaysia.

Kushairi, A., Rajanaidu, N., Jalani, B. S., & Zakri, A. H. (1999). Agronomic performance and genetic variability of dura × pisifera progenies. *Journal of Oil Palm Research*, 11(2), 1-24.

Kushairi, A., Singh, R., & Ong-Abdullah, M. (2017). The oil palm industry in Malaysia: thriving with transformative technologies. *Journal of Oil Palm Research*, 29(4), 431-439. https://doi.org/10.21894/jopr.2017.00017

Larbi, E., Anim-Okyere, S., Danso, F., Danso, I., Afari, P., Nuertey, B. N. and Asamoah,T. E. O. (2013). Effects of planting densities on growth, development and yield of oil palm (*Elaeis Guineensis* Jacq.) in Ghana. *International Journal of Current Research*, 5(10), 2997-3000.

Latif, J., Mohd, N. M., Tayeb, D. M., & Kushairi, D. A. (2003). Economics of higher planting density in oil palm plantations. *Oil Palm Industry Economic Journal*, 3(2), 32-39.

Lee, J. S. H., Ghazoul, J., Obidzinski, K., & Koh, L. P. (2014). Oil palm smallholder yields and incomes constrained by harvesting practices and type of smallholder management in Indonesia. *Agronomy for Sustainable Development*, 34(2), 501-513. https://doi.org/10.1007/s13593-013-0159-4

Maizura, I., Rajanaidu, N., Zakri, A. H., & Cheah, S. C. (2006). Assessment of genetic diversity in oil palm (*Elaeis guineensis* Jacq.) using restriction fragment length polymorphism (RFLP). *Genetic Resources and Crop Evolution*, 53(1), 187-195. https://doi.org/10.1007/s10722-004-4004-0

Marhalil, M., Rafii, M. Y., Afizi, M. M. A., Arolu, I. W., Noh, A., Mohd Din, A., Kushairi, A., Norziha, A., Rajanaidu, N., Latif, M.A. & Malek, M. A. (2013). Genetic variability in yield and vegetative traits in elite germplasm of MPOB-Nigerian dura x AVROS pisifera progenies. *Journal of Food, Agricultures & Environment*, 11, 515-519.

Ming, K. K., & Chandramohan, D. (2002). Malaysian Palm Oil Industry at Crossroads and its Future Direction. *Oil Palm Industry Economic Journal*, *2*(2), 2–7. Retrieved from http://palmoilis.mpob.gov.my/publications/opiejv2n2-10.pdf

Mohamed, N., Barakabah, S. S., & Loong, S. G. (2000). Potential of high-density oil palm plantings in diseased environment. *Planter*, 76(896), 699-710.

Mohd, R., & Mohd, H. H. (2004). The role of leaf area index (LAI) in oil palm. *Oil Palm Bulletin*, (48), 11-16.

Monnahan, P. J., & Kelly, J. K. (2015). Epistasis is a major determinant of the additive genetic variance in *Mimulus guttatus*. *PLoS Genetics*, 11(5). https://doi.org/10.1371/journal.pgen.1005201

MPOB (2001). *Oil Palm Statistics. 21st edition*, Malaysian Palm Oil Board, Malaysia.

MPOB Statistics. (2019). Malaysian Oil Palm Statistics 2018. *Malaysian Palm Oil Board*. Retrieved from www.bepi.mpob.gov.my/index.php/en/statistics/.

MPOB Statistics. (2020). Malaysian Oil Palm Statistics 2019. *Malaysian Palm Oil Board.* Retrieved from www.bepi.mpob.gov.my/index.php/en/statistics/.

MPOB Statistics. (2021). Malaysian Oil Palm Statistics 2020. *Malaysian Palm Oil Board.* Retrieved from www.bepi.mpob.gov.my/index.php/en/statistics/.

Murphy, D. J. (2007). Future prospects for oil palm in the 21st century: Biological and related challenges. *European Journal of Lipid Science and Technology*, 109(4), 296-306. https://doi.org/10.1002/ejlt.200600229

Musa, B., Sritharan, K., & Xaviar, A. (2011). Performance of bi-clonal DxP planting material at United Plantations Berhad. *Proceedings of International Seminar on Breeding for Sustainability in Oil Palm,* 78-100.

Musa, H. (2003). *A Spatial Site Yield Potential Model of Oil Palm*. PhD Thesis. Universiti Teknologi MARA.

Nambiappan, B., Ismail, A., Hashim, N., Ismail, N., Nazrima, D. A. Y. A. N. G., Abdullah, N. I. K., & Hassan, M. (2018). Malaysia: 100 years of resilient palm oil economic performance. *Journal of Oil Palm Research*, 30(1), 13-25. https://doi.org/10.21894/jopr.2018.0014

Nazeeb, M.A.T., Tang, M.K., Loong, S.G. & Syed Shahar, S.A.B. (2008). Variable density plantings for oil palm (*Elaeis Guineensis*) in Peninsular Malaysia. *Journal of Oil Palm Research*. 61-90

Noh, A., Rafii, M. Y., Saleh, G., Kushairi, A., & Latif, M. A. (2012). Genetic performance and general combining ability of oil palm Deli dura x AVROS pisifera tested on inland soils. *The Scientific World Journal*. https://doi.org/10.1100/2012/792601

Noh, A., Rafii, M. Y., Mohd Din, A., Kushairi, A., Norziha, A., Rajanaidu, N. & Malek, M. A. (2014). Variability and performance evaluation of introgressed Nigerian dura x Deli dura oil palm progenies. *Genetics and Molecular Research*, 13(2), 2426-2437. https://doi.org/10.4238/2014.April.3.15

Norziha, A., Fadila, A. M., Marhalil, M., Zulkifli, Y., MOHD DIN, A., Rajanaidu, N. & Kushairi, A. (2020). MPOB oil palm (*Elaeis guineensis* jacq.) germplasms linked to compact trait for high density planting. *Journal of Oil Palm Research*, *32*(3), 394-405. https://doi.org/10.21894/jopr.2020.0050

NST (2017). Celebrating 100 years of Malaysian palm oil (Part 1). *New Strait Times Malaysia*. Retrieved from www.nst.com.my.

Nyquist, W. E., & Baker, R. J. (1991). Estimation of heritability and prediction of selection response in plant populations. *Critical Reviews in Plant Sciences*, 10(3), 235-322. https://doi.org/10.1080/07352689109382313

Okoye, M. N., Okwuagwu, C. O., & Uguru, M. I. (2009). Population improvement for fresh fruit bunch yield and yield components in oil palm (*Elaeis guineensis* Jacq.). *American-Eurasian Journal of Scientific Research*, 4(2), 59-63.

Okoye, M. N., Bakoumé, C., Uguru, M. I., Singh, R., & Okwuagwu, C. O. (2016). Genetic relationships between elite oil palms from Nigeria and selected breeding and germplasm materials from Malaysia via Simple Sequence Repeat (SSR) Markers. *Journal of Agricultural Science*, *8*(2), 159-178.

Olkin, I., & Sampson, A. R. (2001). Multivariate Analysis: Overview. *International Encyclopaedia of the Social & Behavioural Sciences*, Elsevier, Amsterdam.

Ooi, L. C. L., Low, E. T. L., Abdullah, M. O., Nookiah, R., Ting, N. C., Nagappan, J., & Singh, R. (2016). Non-tenera contamination and the economic impact of SHELL genetic testing in the Malaysian independent oil palm industry. *Frontiers in Plant Science*, 7, 771. https://doi.org/10.3389/fpls.2016.00771

Opute, F. I., & Obasola, C. O. (1979). Breeding for short-stemmed oil palm in Nigeria: fatty acids, their significance and characteristics. *Annals of Botany*, 43(6), 677-681. https://doi.org/10.1093/oxfordjournals.aob.a085680

Paterson, R. R. M. (2007). Ganoderma disease of oil palm—A white rot perspective necessary for integrated control. *Crop Protection*, 26(9), 1369-1376. https://doi.org/10.1016/j.cropro.2006.11.009

Djunjana, J., Hadi, P., Joko, H., Iswandar, H. E., Sitepu, B., & Nelson, S. P. (2011). Performance of Sumbio semi-clonal progenesis. *Proceedings of PIPOC 2011 International Palm Oil Congress: Palm Oil Fortifying the World.* Malaysian Palm Oil Board, Malaysia.

Prohens, J. (2011). Plant breeding: a success story to be continued thanks to the advances in genomics. *Frontiers in Plant Science*, 2, 51. https://doi.org/10.3389/fpls.2011.00051

Rafii, M. Y., Isa, Z. A., Kushairi, A., Saleh, G. B., & Latif, M. A. (2013). Variation in yield components and vegetative traits in Malaysian oil palm (*Elaeis guineensis* jacq.) dura × pisifera hybrids under various planting densities. *Industrial Crops and Products*, 46, 147-157.

Rafii, M. Y., Jalani, B. S., Rajanaidu, N., Kushairi, A., Puteh, A., & Latif, M. A. (2012). Stability analysis of oil yield in oil palm (*Elaeis guineensis*) progenies in different environments. *Genetics and Molecular Research*, 11(4), 3629-3641. https://doi.org/10.4238/2012.October.4.10

Rajanaidu, N., & Jalani, B. S. (1994). Prospects for breeding for kernels in oil palm (*Elaeis guineensis*). *Planter*, 70(820), 307-318.

Rajanaidu, N., Ainul, M. M., Kushairi, A., & Mohd Din, A. (2013). Historical review of oil palm breeding for the past 50 years—Malaysian journey. *Proceedings of the International Seminar on Oil Palm Breeding—yesterday, today and tomorrow*, 11-28.

Rajanaidu, N., Kushairi, A., Rafii, M., Mohd, D. A., Maizura, I., & Jalani, B. S. (2000). Oil palm breeding and genetic resources. *Advances in Oil Palm Research*, 1, 171-237.

Rajanaidu, N., Rao, V., Hassan, A. H., & Ong, A. S. H. (1989). Genetic resources-new developments in oil palm breeding. *Elaeis*, 1(1), 1-10.

Rajanaidu, N., Kushairy, A., Mohd. D.A., Marhalil, M., Fadila, A. and Isa, Z.A. (2011). Selection criteria (15-15-15) to develop sustainable oil palm planting materials. *Proceedings of the International Seminar on Breeding for Sustainability in Oil Palm*, 112.

Ramachandran, P., Narayanan, R., Knecht, J.C.X., (1973). A planting distance experiment on dura palms. *Advances in Oil Palm Cultivation.* Incorporated Society of Planters, Kuala Lumpur 72–89.

Rao, V., Soh, A. C., Corley, R. H. V., Lee, C. H., & Rajanaidu, N. (1983). Critical reexamination of the method of bunch quality analysis in oil palm breeding. *PORIM Occasional Paper-Palm Oil Research Institute of Malaysia*.

Rival, A., & Levang, P. (2014). *Palms of controversies: Oil palm and development challenges. Palms of controversies: Oil palm and development challenges*. Center for International Forestry Research (CIFOR). https://doi.org/10.17528/cifor/004860

Ronald, P. (2011). Plant genetics, sustainable agriculture and global food security. *Genetics*, 188(1), 11-20. https://doi.org/10.1534/genetics.111.128553

Rosenquist, E. A. (1986). The genetic base of oil palm breeding populations. Proceedings of *International Workshop on Oil Palm Germplasm and Utilization*. PORIM, Kuala Lumpur.

Sambanthamurthi, R., Singh, R., Kadir, A. P. G., Abdullah, M. O., & Kushairi, A. (2009). Opportunities for the oil palm via breeding and biotechnology. In *Breeding Plantation Tree Crops: Tropical Species* (pp. 377–421). Springer New York. https://doi.org/10.1007/978-0-387-71201-7_11

SAS Institute Inc. (2013). SAS/STAT®13.1 User's Guide. *SAS Institute Inc*.

Singh, G. (1991). Ganoderma-the scourge of oil palms (*Elaeis guineensis*) in the coastal areas (Peninsular Malaysia). *Planter*.

Singh, R. K., & Chaudhary, B. D. (1979). *Biometrical Methods in Quantitative Genetic Analysis*. Kalyani Publishers, India.

Singh, R., Abdullah, M. O., Ti, L. L. E., Nookiah, R., Manaf, M. A. A., & Sambanthamurthi, R. (2015). SureSawitTM SHELL - A Diagnostic Assay to Predict Fruit Forms of Oil Palm. *Oil Palm Bulletin*, 70, 13-16.

Soh, A. C., Mayes, S., & Roberts, J. A. (2017). *Oil Palm Breeding: Genetics and Genomics.* CRC Press, Florida.

Sprague, G.F. & Tatum, L.A. (1942). General vs specific combining ability in single crosses of corn. *Journal of American Society of Agronomy*, 34: 923-932. https://doi.org/10.2134/agronj1942.00021962003400100008x

Sritharan, K., Subramaniam, M., Arulandoo, X., & Yusop, M. R. (2017). Yield and bunch quality component comparison between two-way crosses and multi-way crosses of D×P oil palm progenies. *Sains Malaysiana*, 46(9), 1587-1595. https://doi.org/10.17576/jsm-2017-4609-30

Stuber, C. W. (1994). Heterosis in plant breeding. *Plant Breed Reviews*, 12, 227-251.

Syed, R. A. (1981). Pollinating thrips of oil palm in West Malaysia. *Planter*, 57(659), 62-81.

Tan, G. Y. (1978). Genetic studies of some morphophysiological characters associated with yield in oil palm (*Elaeis guineensis* Jacq.). *Tropical Agriculture*, 55(1), 9-16.

Tan, Y. P., & Ng, S. K. (1976). Spacing for oil palms on coastal clays in Peninsular Malaysia. *Proceedings of Malaysian International Agricultural Oil Palm Conference*. International Society of Planters, Kuala Lumpur.

Tanya, P., Hadkam, Y., Taeprayon, P & Srinives, P. (2013). Estimates of repeatability and path coefficient of bunch and fruit traits in Bang Boet dura oil palm. *Journal of Oil Palm Research*, 25(1), 108-115.

Thomas, R. L., & Hardon, J. J. (1968). An outline of breeding and selection in the oil palm. *Malaysia Agricultural Journal*, 46, 324-331.

Thompson, A. (1931). Stem rot of the oil palm in Malaya. *Bulletin Department of Agriculture, Straits Settlements and F.M.S., Science Series*, *6*, 23.

Tuhina-Khatun, M., Hanafi, M. M., Rafii Yusop, M., Wong, M. Y., Salleh, F. M., & Ferdous, J. (2015). Genetic variation, heritability, and diversity analysis of upland rice (*Oryza sativa* L.) genotypes based on quantitative traits. *BioMed Research International*. https://doi.org/10.1155/2015/290861

Turnbull, N., De Franqueville, H., Fréderic, B., Sriwijeyen, J., Syahputra, I., Cochard, B., & Durand-Gasselin, T. (2014). Breeding methodology to select oil palm planting material partially resistant to Ganoderma boninense. In *5th quadrennial International Oil Palm Conference* (pp. 1–17). Indonesian Oil Palm Research Institute.

Usman, M. G., Rafii, M. Y., Martini, M. Y., Oladosu, Y., & Kashiani, P. (2017). Genotypic character relationship and phenotypic path coefficient analysis in chili pepper genotypes grown under tropical condition. *Journal of the Science of Food and Agriculture*, 97(4), 1164-1171.

United Plantations Research Department (UPRD) Trial Management Manual. (2016). United Plantations field management manual. *United Plantations Berhad*.

United Plantations Berhad (UPB) Internal Report. (2015). Progress in oil palm breeding (Updated as of December 2014). *United Plantations Berhad*.

United Plantations Berhad (UPB) Research Department Annual Report. (2019). Oil palm and coconut breeding progress. *United Plantations Berhad.*

United Plantations Berhad (UPB) External Consultant Report. (2019). A history of breeding in United Plantations Berhad. *United Plantations Berhad*.

Wakefield, E. M. (1920). Diseases of the oil palm in West Africa. B*ulletin of Miscellaneous Information (Royal Botanic Gardens)*. https://doi.org/10.2307/4107530

Woittiez, L. S., van Wijk, M. T., Slingerland, M., van Noordwijk, M., & Giller, K. E. (2017). Yield gaps in oil palm: A quantitative review of contributing factors. *European Journal of Agronomy*, 83, 57-77. https://doi.org/10.1016/j.eja.2016.11.002

Wray, N., & Visscher, P. (2008). Estimating trait heritability. *Nature Education*, 1(1), 29.

Wright, S. (1921). Correlation and causation. *Journal of Agricultural Research*, 20, 557-580.

Yusop, M. R., Sukaimi, J., Amiruddin, M. D., Jalloh, M., Swaray, S., Yusuff, O., & Chukwu, S. C. (2020). Genetic improvement of oil palm through recurrent selection. *The Oil Palm Genome*, 35-46. https://doi.org/10.1007/978-3-030-22549-0_4

Zeven, A. C. (1964). On the origin of the oil palm (elaeis guineensis jacq.). *Grana Palynologica*, *5*(1), 121–123. https://doi.org/10.1080/00173136409429132