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The History and Economic Importance of the Oil Palm

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Abstract

Oil palm is a remarkable crop which in 2017 produced 34% of the world's vegetable oil from 0.36% of the world's agricultural land. The fact that it is a perennial 'tree' crop growing in the humid tropics under high light intensity accounts for the tenfold advantage in oil yield it has over many annual temperate oil crops, per hectare, per year. However, slow breeding cycles in a manually intensive industry are beginning to erode this advantage, and the challenges of climate change have yet to be addressed. The history, economic importance and how research has been applied to improve the productivity and value of the oil palm are reviewed, along with some of the future challenges which research needs to address.

1.1 Introduction

The oil palm is a recent crop success story, particularly in Southeast Asia. While it was widely known and traded during the European industrial revolution, it has only really become a major crop in the last century. This is largely due to the establishment of a wide range of food and nonfood uses and of organised plantations which now produce the majority of the world's traded palm oil and vegetable oil as well. The fundamental basis for this success has been productivity, with oil yields now more than fourfold higher than at plantation establishment in the 1920s (Corley and Lee 1992; Henson 2012—Table 1c). With the current average yields in Malaysia, for example, running at between 3.5 and 4 tonnes oil per hectare per year, this is also around tenfold the yield obtained by some annual oil crops. Moreover, global production of vegetable oil has increased from 90.5 million metric tonnes in 2000/01 to 195.1 million metric tonnes in 2017/18, an increase which has been driven by rising demand and led to palm oil being the most traded global oil (Statistica; 27-08-2018).

While the recent past of oil palm cultivation has been a success story, the future is more uncertain. The yield gap between average yield actually obtained and potential yield is stubbornly static in many countries with the best breeding trials achieving 10–12 tonnes of oil per hectare per year (Henson 2012), and with plantations facing significant palm disease and labour shortage (and cost) threats, oil palm as an industry will need to change significantly in the future if it is to remain competitive and relevant. This is further exacerbated by the poor press particularly relating to deforestation (Vijay et al. 2016) that the oil palm industry receives in some

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of its biggest markets, such as Europe, and the current predictions for climate change and their potential impacts (Paterson et al. 2015).

Corley and Tinker (2015) cover just about everything to do with oil palm and the industry, while Henson (2012) also provides a detailed review of the history of oil palm. Henderson and Obsorne (2000) provide an interesting take on some of the drivers for the industry developing.

The current chapter provides a brief overview of the history and importance of this crop and looks at some of the research history, while also identifying some of the broad challenges for the future.

1.2 Taxonomy, Biology and Distribution

Botanically, 'African oil palm' is classified in order, Arecales; family, Arecaceae; subfamily, Arecoideae; tribe, Cocoseae and in the genus 'Elaeis' with the specific name reflecting the presumed origin in African Guinea, hence *Elaeis guineensis*. It is a monoecious palm with a single growing point, which produces pinnate leaves and bunches of fruit composed of drupes with an endocarp, shell and exocarp. Palm oil comes from the exocarp and kernel oil from the endocarp. For mature palms, bunches can be composed of thousands of fruits and weigh around 50 kg. Individual palms cycle between the production of male and female inflorescences, naturally promoting outcrossing, although some bunches may have small numbers of hermaphroditic flowers (Corley and Tinker 2015).

The wild/semi-wild palm belt in Africa stretches from roughly +10° N to 10° S (although populations are also found in Madagascar, some 20° S, although appear to be relatively genetically distinct (Corley and Tinker 2015—Fig. 1; Bakoume et al. 2015). While *E. guineensis* has been found growing 'wild' in South America, pollen and fossil evidence suggest an African origin (Zeven 1964), with potential transfer of African oil palm to South America in historical time, where it was only picked up industrially in recent years.

A related palm, *E. oleifera,* is also within the genus of Elaeis and is the 'South American oil palm'. The consensus is that the two species split with the breakup of an ancient landmass around 60 million years ago, leading to a speciation by geographical separation without genetic barriers. While hybrids are possible, they can have limited fertility, requiring backcrossing. Production based on F_1 hybrids requires hand-pollination to ensure bunch set. Both species have 16 chromosomes ($2n = 32$), and cytogenetic studies have shown three classes of chromosomes according to length, with similarity between the two species (Maria et al. 1995, 1998; Castilho et al. 2000) although Genomic In Situ Hybridisation (GISH) can be used to distinguish the species (Cheah et al. 2000; Zaki et al. 2017). The recent publication of the genome sequence for *E. guineensis* and comparisons to *E. oleifera* show extensive genomic differences, with substantial variation in the types and quantities of repeat elements between species (Price et al. 2002, 2003; Singh et al. 2013a). Divergence tests suggested a separation time consistent with the geographical separation theory (51 MYR) (Singh et al. 2013a) arguing for a very ancient divergence point, with subsequent genomic evolution.

Genetic diversity analysis from the collections made by Palm Oil Research Institute of Malaysia (PORIM; now Malaysian Palm Oil Board—MPOB) shows the highest level of variation for *E. guineensis* within a Nigerian collection, when compared with 11 other African countries in the palm belt (Maizura et al. 2006) suggesting this region as a possible centre of origin or diversity.

1.3 History and Economic Importance

The first recorded sample of what has been tentatively identified as palm oil was rin from funeral goods interned with a Pharaoh of the Early Dynastic period, around 5000 BCE (Raymond 1961). This suggests that palm oil was recognised to be of value and that human exploitation of palm oil was already underway at that point. Excavations in Ghana have identified preserved samples of palm oil from around 4500 BCE indicating that local exploitation in West Africa was underway at a similar period to the Abydos sample in Egypt. The Abydos sample also argues for the 'trade'or at least movement of oil palm, given that oil palm is unlikely to have ever grown in Egypt. It has been suggested that Arab traders were responsible for taking it to Egypt (Obahiagbon 2012).

The first botanical description was produced by Jacquin (1763) after whom the species is named, with more detailed description by Gaertner (1788) with a recognition of the ability of the palm to produce inflorescences of different sexes. Likely written descriptions by Portuguese explorers date from 1435 to 1460 (Crone 1937). Palm oil was used as part of the food for slaves during the slave trade on the long journey to the New World, but it was really developments in Europe which secured the future of the African oil palm trade. The Industrial Revolution led to the development of saponification and created a major demand for oil palm for lubricants, detergents (e.g. Palmolive, being a well-known soap brand)(Henderson and Obsorne 2000) and other industrial products, and this demand saw trade (still as a cottage industry) increase significantly. Eventually, the trade in oil palm was promoted as a way to suppress the continuing trade in slaves, which was banned in Britain and the British Empire in 1807 through the efforts of William Wilberforce and the abolitionists, but continued clandestinely for many years (Stilliard 1938), with the trade in palm oil seen as a legitimate replacement for shipping slaves from Africa.

The quality of the initial palm oil was poor—it was still essentially a cottage industry, and oil and kernels would be prepared by the villages along the coast or imported from further inland. It was only really with the establishments of the first forts that a more coherent approach to oil palm trade begins, and eventually, this led to the establishment of the first plantations in colonial Africa. In the 1880s, around 75% of Ghana's international trade was in palm oil (http://mofa.gov.gh/site/?page_id=8819). One of the most notable early plantations was set up on a Belgian concession in the Congo (Democratic Republic of Congo at Binga) in 1935 by Sir William Lever, who founded the British part of Unilever (Henderson and Obsorne 2000).

Since these initial stages of industrial development, considerable progress has been made, although the focus of the industry shifted after World War II towards Southeast Asia, with significant expansion in the 1960s and 1970s, where plantations established in Malaysia and Indonesia were highly productive and now produce 85% of palm oil in the world.

A concern of the current oil palm industry is a relatively restriction origin for some of the most important origins in the current commercial use. The final commercial palm is a hybrid between thick-shelled *dura* palms and shell-less *pisifera* pollen parents. This single gene trait has had more influence on palm breeding than any other (Beirnaert and Vanderweyen 1941; Singh et al. 2013b). According to pedigree, the main Deli *dura* population (seed parent) is derived from four palms introduced into the Bogor Botanic Garden in Indonesia in 1848. Offspring of these were grown in the Economic Garden and were used by many plantations for selection, although selection criteria adopted were often different, leading to a number of Breeding Populations of Restricted Origin (BPRO) (Rosenquist 1986). On the pollen side, the offspring of a palm called 'Djongo'—the 'best'—was imported from Congo and eventually came to represent the AVROS *pisifera* origin with 75% of the genetic material derived from a single palm. This is now the most important *pisifera* source (Corley and Tinker 2015). However, as oil palm is naturally outcrossing, going through cycles of male and female inflorescence production, it seems very likely that early attempts at controlled pollination involved relatively high levels of pollen contamination. The introduction of the pollinating weevil, *Elaeidobius kamerunicus* into Southeast Asia in 1981 (Syed 1982) led to high levels of *dura* contamination in controlled commercial seed production, so the original African sources of germplasm, where the pollinating weevils were endemic, are likely to represent a range of material from different pollen sources, even if the maternal palm was correctly selected.

Despite a technically very narrow pedigree, the performance of the introduced thick-shelled *dura* fruit type was sufficiently good (or the tested African thin-shelled *tenera* sufficiently bad) that Malaysia and Indonesia only moved reluctantly from planting thick-shelled *dura* as commercial material to thin-shelled *tenera* in the 1960s. This shift increases oil yields through reducing shell thickness and increasing mesocarp oil by 30%. It certainly is also the case that the environment in Southeast Asia is more favourable than much of Africa, being humid with high rainfall, stable temperatures, good light and, perhaps most importantly, little in the way of seasonal variation, so that palms can produce all year round. Today, Southeast Asia accounts for around 90 per cent of world production and 61% of world trade. In 2017, 67.92 million tonnes of palm oil were produced, together with 7.25 million tonnes of palm kernel oil, compared with 53.94 million tonnes of soybean oil, the second-largest oil producer. Oil palm is planted on 19.04 million hectares of world agricultural land (0.36%). Oil palm alone accounts for 34% of world production (Kushairi et al. 2018).

Oil palm is also unusual in that it produces two oils: mesocarp oil from the fruit pericarp and kernel oil from the kernels. These are extracted separately and have different compositions, with ‘crude palm oil’: CPO—mesocarp oil—being roughly 50% palmitic, 40% oleic and 10% other unsaturated oils. This makes it more solid at (nontropical) room temperatures, and it is often fractionated into oleic and stearic fractions. The kernel oil is formed of saturated short-chain fatty acids, which provide a composition quite similar to coconut oil, and it is often used in ice creams and coffee whiteners. Because of the desire to separately extract the two oils, the processing is slightly more complicated than for temperate oilseed crops. In addition to the oil itself, CPO is high in carotenoids and tocopherols and tocotrienols. The first can be used for Vitamin A production and the latter ones for Vitamin E production. The crushed seed cake can be fed to animals (but is a relatively poor feed), and palm oil can be converted to biodiesel, while there is also some use of the palm trunk for construction materials (Soh et al. 2017a).

1.4 The Challenges

Breeding in any tree crop is often a long-term process, and oil palm is no exception. The understanding that the control of the fruit shell thickness was under control of a single gene means that almost all commercially planted material today is of *tenera* hybrids. In practice, this has led to variations on Recurrent Reciprocal Selection (RRS) and Family and Individual Selection (FIS) schemes, or their combinations (Soh et al. 2017b). Because of the requirement for hybrids and the difficulty predicting breeding values in the *pisifera* line (many origins are female sterile due to bunch abortion), the actual breeding cycle for oil palm is long (between 12 and 19 years). Despite the long cycles, an experiment evaluating different rounds of selection of material suggests that in four generations, the yield had quadrupled, compared to unimproved material. Roughly half of this was attributed to genetic improvement and half to improvements in management and agronomy (Corley and Lee 1992).

The main factors influencing response to breeding selection are the heritability of the trait and the selection intensity imposed. ‘Oil yield per palm’ has a lower heritability than ‘oil-to-mesocarp ratio’, and greater response to selection would be expected by focusing on more heritable components of the desired oil yield trait. This led to the idea of bunch analysis (Blaak 1965) which breaks down oil yield into the component traits which underlie it. This approach to assessing palm value in a breeding programme has been largely unchanged since it was originally adopted. In a breeding trial, it is possible to measure fresh fruit production from individual palms, but it is not possible to bunch analyse all of the bunches from a palm. This leads to a sampling approach, where the value of a palm is only judged when a minimum of three bunches have been analysed (and preferably over five) and often only as a part of assessing the quality of the parental palms of a family. While this appears potentially limiting in terms of selection accuracy, it clearly works in practice, with yield potential continuing to advance. Finding a less labour-intensive or more accurate approach could be an important area to improve the efficiency (and potentially accuracy) of future selection (Corley 2018a, b).

The presence of only a single vegetative meristem at the apex of the palm spurred the development of tissue culture approaches to allow the clonal multiplication of this heterozygous palm. In practice, the methods developed by a number of organisations in the 1960s and 70s focused around somatic embryogenesis with the intention to mass produce the elite palms clonally (Jones 1974; Rabechault and Martin 1976). Regeneration of palms is relatively slow (around two years in many cases), and there is a strong genotype dependence for embryogenesis. However, after a series of hormonally induced stages, the process works and can be highly productive. It faces two main problems: accuracy of predicting the performance of clones and, more critically, the development of abnormality for flowering in clones. The latter was first reported in Unilever material when it was observed that continuous culturing of material in tissue culture led to progressively more palms which produced ‘mantled fruits’ where the rudimentary androecium in female inflorescences develops into supplementary carpels (Corley et al. 1986). The problem that this leads to is poor fruit set and bunch abortion. While it has been shown that there is clearly a general decrease in methylation during tissue culture which can persist after regeneration, the oil palm at the sequence level is remarkably stable. The locus responsible for the mantling phenotype has recently been identified. This was predicted to be a homeotic floral gene from soon after the phenomenon was first reported, but has only recently been elucidated as changes to methylation patterns (CHG) in a retrotransposon element in an intron of the *Deficiens* gene of oil palm (Ong-Abdullah et al. 2015, 2017). Had this locus not been sensitive to tissue culture, the current planting material and breeding schemes in oil palm would have been very different today. However, the development of an accurate diagnostic test could allow the potential of clonal propagation to be finally realised, and developments in the field of molecular markers and (in the future) phenotyping could address the relatively poor correlation between parental palm performance (Ortet) and clonal offspring performance (Ramet).

1.5 Overseeing the Challenges

A major step forward was the public release of the genome sequence of a *pisifera* palm by the Malaysian Palm Oil Board (MPOB) (Singh et al. 2013a) quickly followed by reports of the cloning of the genes for shell thickness (Singh et al. 2013b), *virescens* (Singh et al. 2014) and identification of the gene responsible for the mantled (abnormal) flowering form which has dogged the application of tissue culture for over 40 years (Ong-Abdullah et al. 2015).

The identification of these genes potentially allows the development of perfect markers, which test the actual site of mutation responsible for the phenotype. Commercial diagnostic test kits have been developed for shell and fruit colour assay, while it is under development for clonal abnormality. However, the accuracy of such kits depends on the specific allelic variant present in the different sources of germplasm, and it may be a number of years before the kits are 100% accurate and account for all variants within oil palm germplasm.

Alongside the identification of these major genes which influence oil palm tissue culture and breeding, other groups (and notably Sime Darby Plantations in Malaysia) have focused on the development of high-density marker systems and the routine application of marker information integrated with the breeding programme. This has allowed the integrated use of ‘Omic’ technology in gene discovery (Teh et al. 2017a), but perhaps more importantly the development of association genetic analysis and the testing of genomic selection methods. Genomic selection and variants of what might be termed ‘informed genomic selection’ where GWAS results are used to inform the models created, address the biggest hurdle for oil palm breeding- selection cycle length (Wong and Bernado 2008; Kwong et al.

2016, 2017; Cros et al. 2015a, b; Cros 2017a, b; Teh et al. 2017b).

However, the biggest hurdle overall facing the industry at the moment in Southeast Asia is cost of labour for harvesting, which is highly manual at the moment. The leaf subtending the bunch needs to be removed using a curved blade on an aluminium pole, before the bunch stalk can be cut. For older plantations, the bunch can fall several metres, and many fruits detach on landing. This necessitates the collection of loose fruits from the ground as well as the impact activating the lipases which begin to degrade the quality of the oil in the mesocarp.

Further domestication is clearly a major target for future breeding and application of biotechnology with the design of new ideotypes (e.g. Corley 2017), including a redesign of the bunch structure itself. This could be an important step forward to reduce the dependency on manual harvesting and to modernise plantation practices. At the same time as there is a need to reduce inputs for increased plantation sustainability (both ecological and economic), the effects of climate change are beginning to be felt, particularly in the form of periods of relative drought in Malaysia and these are predicted to impact further (Paterson et al. 2015; Soh et al. 2017c). This makes breeding for a degree of drought tolerance more important for some regions or for the more extensive use of water management and, perhaps in the longer term, irrigation, which will add to costs. The recent drought episodes in Malaysia have seen a direct fall in fruit production as well as potentially storing up longer term problems (stress can lead to a decreased sex ratio, with more male influorences being formed and emerging over two years later).

1.6 Conclusion

While oil palm faces a potentially difficult future given the number of pressures on it, ultimately, it is likely to survive as an industry. The hard fact is that oil palm produces 34% of the world's vegetable oil on 0.36% of the agricultural land. There is, at this point in time, no crop which can currently replace it for productivity and which is economically viable. With the rapid advances in genetic technology (and particularly the next-generation sequencing and 'Omics'), the tools are available to meet these challenges from a breeding perspective. Supplementing these with specific applications of tissue culture and gene editing provides a powerful tool kit to develop future oil palm. There is a clear need for better phenotyping methods and the development of high throughput approaches appropriate for oil palm (so called phenomics), but the foundations for an ecologically and economically sustainable industry do exist and through hard work and focused application of science, can be achieved (Soh et al. 2017c). While improvements in oil palm are required, looking again at the economics of the plantation and land use may allow multiple crops to be grown, improving plantation economic sustainability and also agricultural biodiversity.

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