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PROCESSING OF UNDER AND OVERRIPE OIL PALM FRUITS AND ITS EFFECTS ON YIELD AND OIL QUALITY

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ABSTRACT

Fresh fruit bunches (FFB) harvested between 19 and 24 weeks after anthesis (WAA) were processed in a laboratory to extract crude palm oil (CPO). The CPO was mechanically extracted from oil palm fruits at various stages of maturity and analysed for its physico-chemical properties, including deterioration of bleachability index (DOBI), carotene content, total chloride content (TCC) and chlorophyll (CHL) pigments. Underripe fruits at 19 WAA had a higher moisture content (MC) (72.69%) compared to ripe fruits at 23 WAA (26.84%). As the fruits fully matured, the oil content (OC) increased, exceeding 40.00% of the total fruit mass. The quality of CPO extracted from underripe fruits was characterised by lower carotene content and DOBI values (175.00 mg kg^{-1} and 2.19, respectively), but higher levels of CHL pigments (5.38 mg kg^{-1}) and TCC (7.00 mg kg^{-1}). In contrast, the CPO from fully developed fruits exhibited higher carotene content and DOBI values (762.00 mg kg^{-1} and 3.45, respectively), while CHL pigments and TCC decreased. Good quality CPO is identified by a higher DOBI value and lower CHL pigments and TCC. A higher DOBI value indicates easier bleaching and refining, while lower CHL pigment levels contribute to better oxidative stability.

Keywords: anthesis, chlorophyll, total chloride content, underripe fruits.

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INTRODUCTION

Fresh fruit bunches (FFB) are harvested when they reach optimal ripeness. The degree of FFB ripeness can be categorised into unripe, underripe, ripe and overripe. The optimal ripeness of FFB is reported to be between 20-22 weeks after anthesis (WAA), based on oil content (OC) in the fruit (Prada *et al*., 2011; Sambanthamurthi *et al*., 2000). At palm oil mills, FFB maturity assessment is carried out by graders based on the number of loose fruit sockets on the bunch. The FFB is considered overripe when there are more than five loose fruit sockets on the bunch, while ripe FFB exhibits two to five loose sockets. The FFB are categorised as unripe and underripe when no loose fruit sockets are observed on the bunch (Malaysian Palm Oil Board [MPOB], 2015). To differentiate between unripe and underripe FFB, the colour of the fruits plays an important role, with unripe fruits usually being yellow, while underripe fruits are yellowish-orange in colour. The processing of unripe FFB has been associated with low OC, resulting in a lower oil extraction rate (OER) at palm oil mills (Basiron, 2007; Parveez *et al*., 2023). In addition to low OER, other pertinent issues related to unripe fruit processing include inferior crude palm oil (CPO) quality (Tan *et al*., 2023) and low kernel extraction rate (KER) (Amir *et al*., 2022).

Chlorophyll (CHL) and carotene content in CPO are some of the quality issues reported to be associated with the degree of ripeness of oil palm fruit (Siew, 2001; Tan *et al*., 2023). CPO extracted from fruits at 17 WAA maturity showed higher CHL content but lower carotene content compared to CPO extracted from fruits at 23 WAA maturity (Tan *et al*., 2023). At 19 WAA, FFB produced CPO with as high as 12 mg kg^{-1} CHL content (Tan *et al*., 1997). Conversely, CHL was undetectable in CPO extracted from 22 WAA fruits. It was also highlighted that CPO extracted from underripe fruits exhibited low deterioration of bleachability index (DOBI), which is associated with lower

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carotene content (Siew, 2001; Tan *et al.*, 1997). Oils with significant CHL content could lead to inferior quality due to its adverse effects on bleachability, hydrogenation and oxidative degradation (Tan *et al.*, 2023). Higher CHL content in crude canola oil resulted in dull, dark brown refined oil and required large amounts of bleaching earth for refining (Diosady, 2005).

The presence of chlorinated compounds in CPO has been comprehensively examined by Nagy *et al.* (2011), while Tiong *et al.* (2018) identified different types of organochlorine compounds in CPO derived from oil palm fruits at different stages of maturity. The chlorinated compounds can be categorised as organic and inorganic. The most abundant organochlorine in CPO is primarily phytosphingosines (Nagy *et al.*, 2011), which have been found to be the most reactive chlorine precursor in the formation of 3-monochloropropane-1, 2-diol esters (3-MCPDE) (Tiong *et al.*, 2018). The occurrence of sphingolipid organochlorine compounds is dependent on the OC in the mesocarp, which correlates with the stages of maturity and fruit ripeness (Tiong *et al.*, 2018). On the other hand, the inorganic chlorines are mostly found in the form of iron (II), iron (III), magnesium and calcium chloride.

Studying the processing of under and overripe fruit is important to address the potential adverse effects on oil quality and to explore ways to mitigate the formation of contaminants throughout the supply chain. The reactive chlorinated compounds, which are associated with the formation of 3-MCPDE, are closely linked to the ripeness of the fruits. Colour darkening or colour reversion of refined oil may be caused by the CHL content in CPO, which originates from underripe fruit processing.

MATERIALS AND METHODS

Materials

A total of 18 commercial oil palm trees of *tenera* (DxP) variety, 15 years old, were identified at MPOB's Kluang Research Station, Johor, Malaysia as the source of FFB (*Figure 1*). The oil palm trees were grown on Rengam and Jerangau soils, with the Rengam series providing well-drained, loamy conditions and the Jerangau series contributing heavier, clayey soil with more water retention. These soil types were selected to evaluate their influence on oil palm fruit development at various maturity stages. The selection of oil palm trees was based on the availability of female flowers during the field trials. The flowers were marked as Week-0 immediately after anthesis. At the end of each maturity stage, FFB from 19-24 WAA FFB were harvested and delivered to the laboratory for further processing. The FFB from each maturity stage were collected in triplicate. All chemicals used were of analytical and GC grades.

Methods

Extraction of CPO. The FFB was first chopped to obtain the spikelets before undergoing sterilisation in an autoclave at 120ºC for 20 min. The mesocarp and kernel of the fruits were then separated using a knife. The mesocarp was mechanically pressed using a hydraulic press to obtain crude oil, which was later centrifuged at 10,000 rpm using a Thermo Fisher Scientific Floor Model Centrifuge (Sorvall RC 5C+, Massachusetts, USA) to separate water and sludge. Finally, the CPO was filtered using a Whatman No. 1 filter paper and stored in a freezer at -20ºC prior to subsequent analyses.

Moisture content (MC) and OC. The fruits were sampled from the FFB and the mesocarp was sliced into small pieces. The MC of the fruits was determined by heating the mesocarp samples at 105ºC until constant weight was achieved. The mesocarp samples were kept in an oven for 24 hr and the MC was recorded as an average from 12 measurements.

The determination of OC was carried out using two units of the Gerhardt Soxtherm 6-place apparatus (Model SOX416, Bonn, Germany). About 10 g of dried mesocarp sample was placed into 12 extraction thimbles. The oil from the dried mesocarp was extracted using petroleum ether at 150ºC for 8 hr. The weight of the oils was recorded as an average from 12 measurements.

Analyses of oil samples. The DOBI, carotene and CHL contents were analysed according to the International Organization for Standardization (ISO) Method (ISO 17932:2011) (ISO, 2018) and American Oil Chemists' Society (AOCS) Official Method (Cc 13i-96) (AOCS, 2015), respectively. Analysis of total chloride content (TCC) was carried out using American Society for Testing and Materials (ASTM) D 4929-04, Method B for crude oil (ASTM, 2004), with slight modifications (Hammid *et al.*, 2022).

Statistical analyses. Analyses were conducted in triplicate and reported as means ± standard deviation (SD) of independent analyses. Data obtained from the analyses were subjected to one-way analysis of variance (One-way ANOVA) with Fisher's Multiple Comparison to determine significant differences among the samples, defined at a 95% confidence interval (p<0.05). The statistical analyses were performed using a Minitab software Version 16 (Minitab Inc., State College, PA, USA).

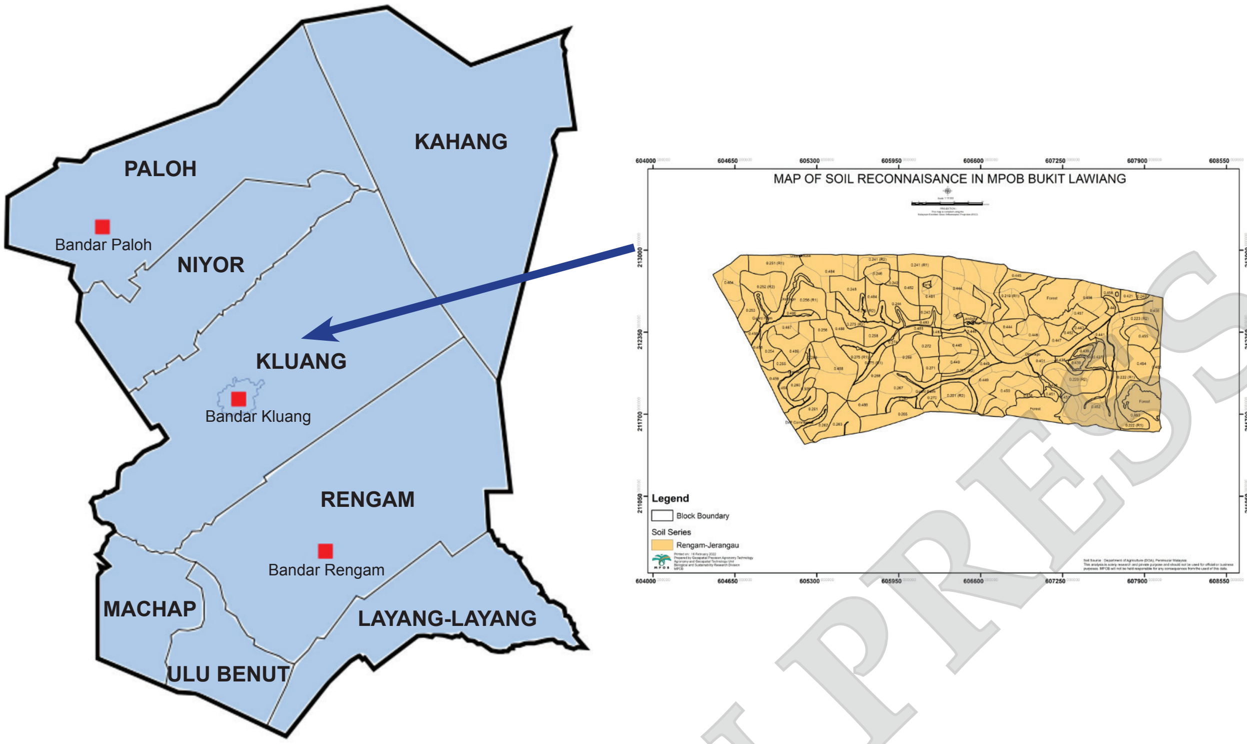

Figure 1. Location of the sampling of FFB.

RESULTS AND DISCUSSION

Biosynthesis of oil in oil palm mesocarp begins from 15-16 WAA and increases over the next 6-7 weeks (Tan *et al.*, 2023). *Figure 2* illustrates the OC and MC in the fruits at different degrees of maturity. At the early stages of fruit maturity between 19-21 WAA, biosynthesis of the oil was almost stagnant and the OC was not significantly different (p>0.05), hovering between 14.7%-17.8%. However, as the fruit ripened, the OC increased significantly (p<0.05), with the highest OC of 43.9% reached at 23 WAA, slightly reducing a week later at 24 WAA. On the other hand, MC in the mesocarp peaked at the early stages of fruit maturity. The maximum MC in the fruit was observed between 19-21 WAA before rapidly decreasing between 22-24 WAA. Hence, it could be suggested that the optimal harvesting time is 23 WAA, when the OC is highest while the MC shows the opposite trend. At 24 WAA, the fruits had entered an overripe period where the OC had slightly reduced.

It was reported that the accumulation of oil peaked at 22 WAA and slightly decreased at 24 WAA (Prada *et al.*, 2011). The reduction in OC at 24 WAA was in agreement with the over-ripening of fruit and bunches. Bafor and Osagie (1986) and Oo *et al.* (1986) reported that the highest OC in mesocarp occurred at 22 WAA. However, Sambanthamurthi *et al.* (2000) found that the highest OC was achieved at 20 WAA. Variations in OC could be attributed to differences in the age of the oil palm, cultivar and environmental conditions (Bafor & Osagie, 1986).

Figure 3 demonstrates the changes in carotene content and DOBI values during the ripening of the fruits. Carotene content and DOBI values significantly increased (p<0.05) as the fruits developed to maturity. As shown in *Figure 3*, the carotene content and DOBI were lowest during the early stages of fruit development. As the fruit ripened, carotene were continuously produced, concurrently with lipid synthesis. At the optimum harvesting time of 23 WAA, the carotene content and DOBI were found to be 535 mg kg^{-1} and 2.85, respectively, which are within the range of typical values for CPO quality. Unlike other CPO qualities, carotene content and DOBI kept increasing a week after the optimum harvesting time (24 WAA). This similar trend was also reported by Tzuan *et al.* (2022). Ruswanto *et al.* (2020) highlighted that fruit quality is one of the most important factors affecting the DOBI values of the extracted oil. Low DOBI values are observed in CPO extracted from unripe or underripe fruits, particularly those that are still blackish in colour. Black bunches may have CPO with a DOBI below 1.5, whereas CPO extracted from fruits at optimum ripeness could exhibit a DOBI above 3.0. The free fatty acid (FFA) content was also higher in overripe fruits (Soetrisno *et al.*, 2024).

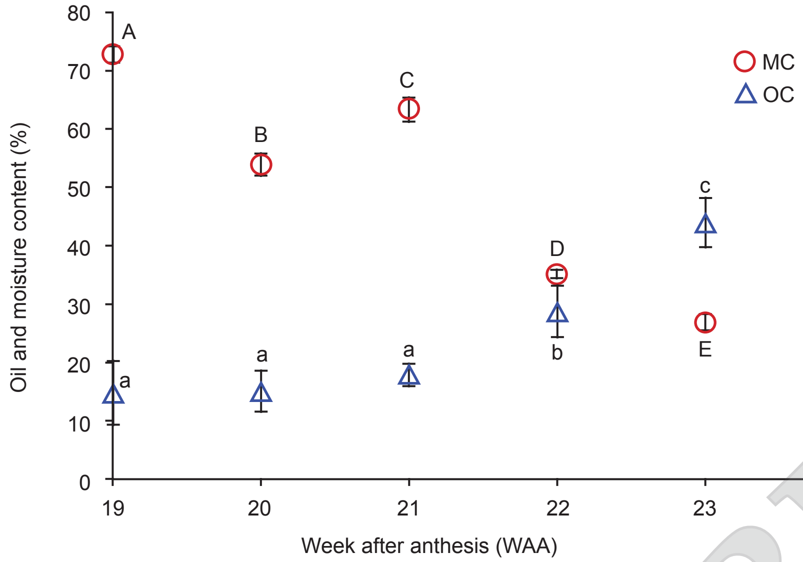

Figure 2. Transient of MC and OC of FFB harvested at different degrees of maturity. Values with different letters are significantly different (p<0.05).

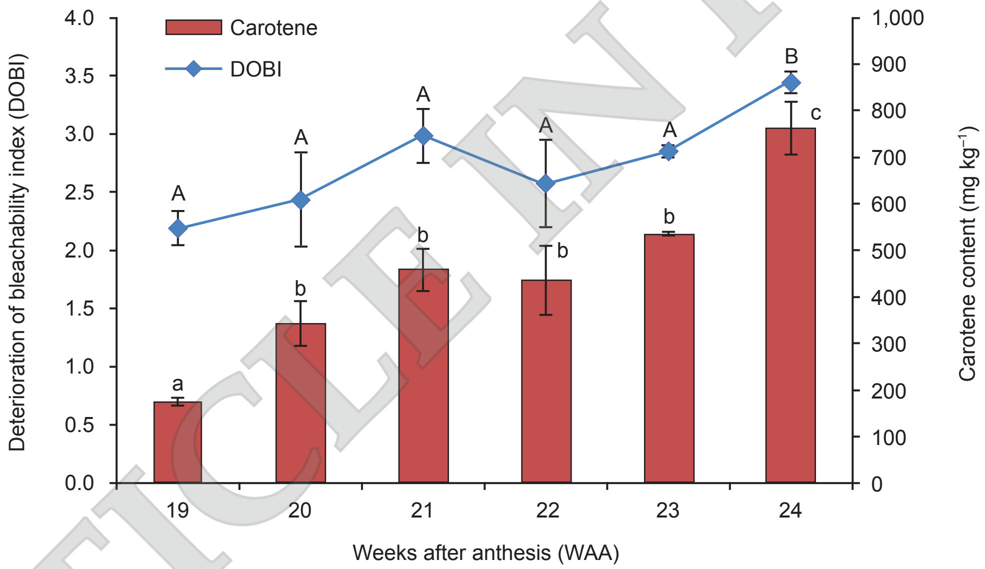

Figure 3. Changes in carotene content and DOBI during the ripening of fruits. Values with different letters are significantly different (p<0.05).

Chlorophylls (CHL) are another group of pigments in CPO besides carotenoids. CHL are fat-soluble pigments and are undesirable because of their adverse effects on oxidative deterioration and bleachability (Li *et al.*, 2019; Tan *et al.*, 2023). CHL contents in CPO extracted from underripe fruits were significantly higher (p<0.05) compared to mature fruits (*Figure 4*). During the early stages of maturity (19-21 WAA), the CHL content was highest and began to decrease as the fruits ripened to 22-24 WAA. The results of this study support the earlier findings by Tzuan *et al.* (2022), where CHL was found to be higher in immature fruits. As the fruit fully developed (23-24 WAA), the CHL content was almost undetectable.

The surface of oil palm fruits is usually green to black in colour during the unripe stage due to the high CHL content. During the ripening stage, the fruits turn orange-red in colour due to the accumulation of carotene and the degradation of CHL. At the early stages of fruit development, the CHL on the FFB surface is actively involved in photosynthesis, producing energy essential for the growth and fruit development. As the fruit matures, the CHL becomes less crucial, and the fruit begins to accumulate phytonutrients and other compounds, such as carotene, which give it its final orange-red colour (Tan *et al.*, 2023).

TCC in CPO extracted from fruits at different degrees of ripeness is illustrated in *Figure 5*. The TCC in CPO extracted from underripe fruits between 19-21 WAA was significantly higher ($p<0.05$) compared to the TCC in CPO extracted from ripe and overripe fruits of 22-24 WAA. The TCC trend corresponded to the OC and MC in the fruits (*Figure 2*). It was noted that fruits with maturity between 19-21 WAA had higher MC as well as significantly higher TCC in the extracted CPO. When the fruits ripened to 22-24 WAA, a significant reduction in MC and TCC was observed. According to Tiong *et al.* (2021), CPO extracted from unripe fruits (18-19 WAA) contained higher amounts of organochlorines, namely fatty acids, diacylglycerols and other unknown organochlorines. As the fruit fully developed, the reduction of organochlorine content was significant ($p<0.05$).

Chloride is considered a beneficial macronutrient for plants. It increases fresh and dry biomasses, promotes greater leaf expansion, enhances the elongation of leaf and root cells, improves water relations, increases mesophyll diffusion of carbon dioxide (CO_2) and boosts water- and nitrogen-use efficiency (Colmenero-Flores *et al.*, 2019). In the case of oil palm, chloride may have been metabolised for the development of oil palm fruits, which could lead to reduced TCC in the ripened fruits (Viégas *et al.*, 2020).

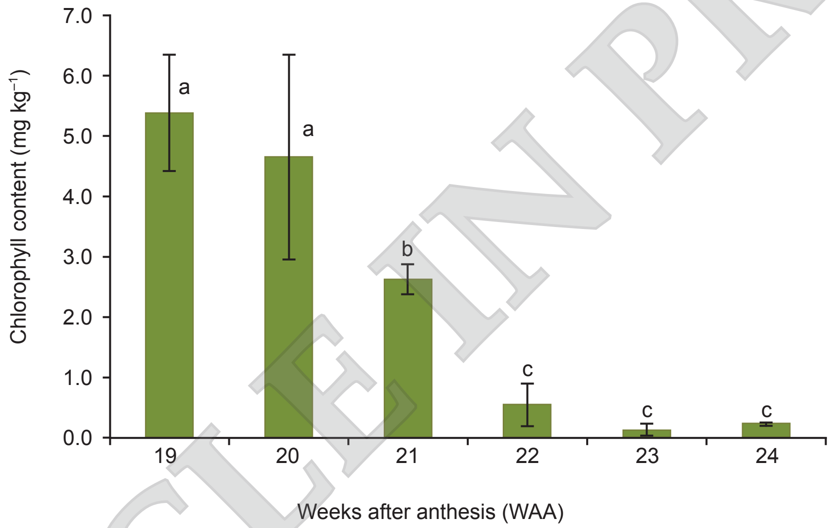

Figure 4. Changes in CHL content during the ripening of fruits. Values with different letters are significantly different ($p<0.05$).

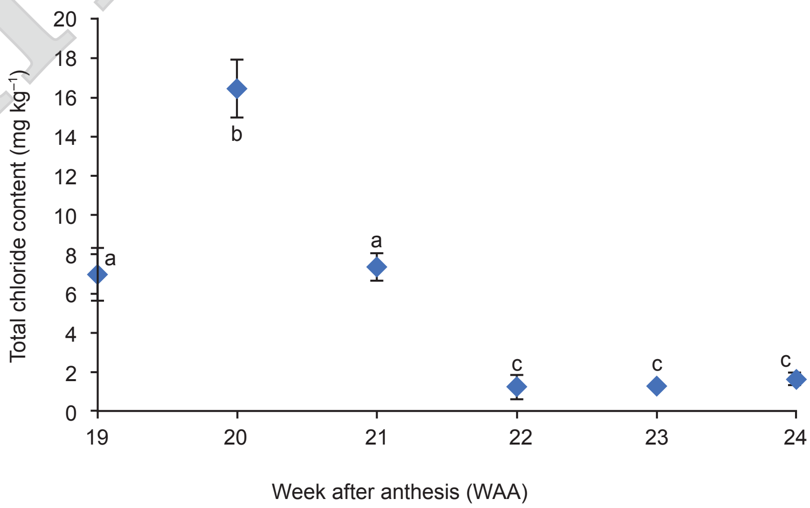

Figure 5. TCC in CPO extracted from fruits at different degrees of maturity. Values with different letters are significantly different ($p<0.05$).

CONCLUSION

Underripe fruit processing presents several challenges that require remedial action. The underripe fruits contained higher MC than oil. CPO extracted from underripe fruits exhibited low carotene content and DOBI values but higher levels of CHL pigments and TCC. As the fruit development progressed, the carotene content and DOBI values of the extracted CPO increased, while the CHL pigments and TCC were depleted in the oil extracted from ripe fruits. The presence of CHL pigments may affect colour while TCC contributes to the formation of 3-MCPDE in refined oil. Therefore, processing of underripe fruits should be avoided to safeguard the quality of CPO.

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