

GENETIC DIVERSITY OF MPOB-ZAIRE OIL PALM (*Elaeis guineensis* Jacq.) GERMPLASM POPULATION BY MULTIVARIATE ANALYSIS

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ABSTRACT

Information on the genetic diversity of the oil palm germplasms is important for the establishment of an ex-situ core collection. In this study, the assessment of genetic diversity in the MPOB-Zaire oil palm germplasm collection may prove to be valuable in developing appropriate sampling strategies for conservation. Data for 18 phenotypic variables for 55 populations were analysed for principal component analysis (PCA) and cluster analysis (CA). Five paramount principal components with eigenvalues >1.0 accounted for 82.7% of the total variability. PC1 revealed the highest contribution and predominantly attributed to average bunch weight, leaf area index, and bunch weight variables. PC2 was highly associated with oil to bunch, mesocarp to fruit and oil to dry mesocarp. The evaluated populations were grouped into two major clusters, each comprising a few sub-clusters based on phenotypic variables. The study revealed that the MPOB-Zaire germplasm has potential, where selected populations e.g. ZER21, which show dwarf (28.12 cm yr⁻¹) and high kernel (8.03%) characteristics can be used in introgression programmes to further improve advanced breeding lines and develop new breeding material. These results may assist in the selection strategies of populations for regeneration purposes and secure a greater range of diversity compared to sampling at random. Molecular-based diversity patterns could be integrated in future to effectively conserve and exploit.

Keywords: cluster analysis, core collection, oil palm, principal component.

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INTRODUCTION

The oil palm (*Elaeis guineensis* Jacq.) was introduced to Southeast Asia as an ornamental plant by the British in the early 1870s (Kushairi and Parveez, 2017). In 1917, oil palm was planted commercially and is now the foundation of Malaysia's economy (Kushairi and Parveez, 2017). Malaysia was the world's largest producer of palm oil before being overtaken by Indonesia in 2006, both have tropical climates that are conducive to oil palm plantation.

The oil palm plantation grew rapidly from 54 638 ha in 1960 to 5.74 million hectares in 2021 (Parveez *et al.*, 2022). Palm oil is known as a valuable commodity, used in the production of diverse sectors from food to cosmetics and personal care products, as well as in animal feed and biofuel. By the end of the century, the global demand for vegetable oil is expected to reach 240 million tonnes (Corley, 2009). The high productivity and low production costs of oil palm enable it to meet rising oil demand with the least amount of negative impact on the environment (John-Martin *et al.*, 2022).

Good planting materials are heavily reliant on gene pools that can offer diversity, which is the backbone of plant breeding (Acquaah, 2012). Since 1973, the Malaysian Palm Oil Board (MPOB) has

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expanded the genetic resources of oil palm breeding materials by extensively collecting wild germplasm from oil palm origin areas, which includes the 11 African countries: Nigeria, Cameroon, Zaire, Tanzania, Madagascar, Angola, Senegal, Gambia, Sierra Leone, Guinea and Ghana (Rajanaidu *et al.*, 2017). *Ex-situ* living collections of oil palm germplasm are exclusively maintained in the fields at the MPOB Kluang Research Station in Malaysia. These collections provide an accessible resource for the evaluation, characterisation, and utilisation to improve the current planting materials. However, field gene bank upkeep is costly in terms of labour, field management and large land requirement. Maintaining germplasms through this approach also involves the risk of attacks by pests and diseases that could potentially lead to the loss of these valuable genetic resources. Conservation of oil palm genetic resources is critical to establishing a reservoir of genes for the creation of novel traits such as high yield, dwarf palm, long stalk, large kernel, oil quality, disease resistance, drought and flood tolerance. Exploiting the genetic diversity of the MPOB-Zaire oil palm germplasm is important to understand its characteristics and population structures. The establishment of a core collection would lower the cost of maintaining the oil palm germplasm by conserving the maximum genetic resource with minimal land space.

Zaire, now known as the Democratic Republic of Congo (DRC), is geographically the second-largest country in Africa. Distribution of grove palms in Central Africa focuses mostly in Zaire and Angola (Corley and Tinker, 2016). The bulk is located between 3° N and 7° S, but there are a few scattered palms as far south as 15° S. Semi-wild palms exist on the Congo-Uganda border, but the weather in most of eastern Africa is not suitable for growing commercial oil palms; it is either too arid, too high in altitude, or both. In the early 1900s, most of the African oil palm plantation activity was in the Congo, where local farmers were encouraged to plant oil palms (Berger and Martin, 2000). Later, in the 1930s, the major scientific discovery of the relationships between *tenera*, *pisifera* and *dura* was found in the Belgian Congo at the *L'Institut National pour l' Étude Agronomique du Congo belge* (INEAC), Yagambi (Susan, 2003), which drove plantation development in the country and later, in the global oil palm industry. In 1984, MPOB, in collaboration with Unilever, conducted the first systematic prospection of the oil palm germplasm in Congo (Rajanaidu *et al.*, 2017).

Evaluation of genetic diversity based on morphological traits to ease the utilisation and conservation of germplasm materials is important for breeding programmes. Multivariate analysis is a group of methods that are often used to analyse the traits of breeding materials. It is important to

classify germplasm, organise variability among accessions, and analyse genetic relationships among traits (Zafar *et al.*, 2008). Principal component analysis (PCA) is one of the multivariate statistical techniques used to reduce the dimensionality of large data sets. It accomplishes this by computing little explaining variables that accurately describe the original data set. Hierarchical cluster analysis (HCA) however categorises similar observations based on the observed values of variables for each individual in the dataset. PCA and HCA have been successfully applied in crop germplasm evaluation for many years including pigeon pea (Hemavathy *et al.*, 2017), rice (Mvuyekure *et al.*, 2018), coffee (Ferraz *et al.*, 2019) and cotton (Ullah *et al.*, 2022). Both methods have been used to depict oil palm germplasm collected from Nigeria (Li-Hammed *et al.*, 2016), Sierra Leone (Suzana *et al.*, 2016), Ghana (Sapey *et al.*, 2017), India (Balakrishna *et al.*, 2017), Senegal (Myint *et al.*, 2019) and Tanzania (Suzana *et al.*, 2020). In this study, principal component (PC) and cluster analyses were used to classify and group MPOB-Zaire oil palm *dura* germplasm samples based on morphological traits and to also evaluate their genetic diversity.

MATERIALS AND METHODS

The prospection for oil palms in Zaire covered more than half of the country's area. Zaire has a dense tropical rainforest and experiences a tropical climate with two distinct seasons, dry and wet. During the expedition, 369 open-pollinated bunches (283 *dura* and 86 *tenera*) were collected, including 40 samples assembled by the Institute for the Environment and Agricultural Research Stations (INERA) in Bas-Zaire. Five to ten palms were randomly sampled at 56 sites (each defined as a population) (Rajanaidu *et al.*, 2017) (Figure 1). However, one population (ZRE45) did not survive due to unsuccessful germination. Seedlings from 55 Zaire germplasm populations were planted in four experimental trials, designated as trials 0.220 (17 populations), 0.221 (15 populations), 0.222 (12 populations) and 0.223 (11 populations), incorporating two standard cross progenies, MS3516 and MS3554. The planting design involved two replicates with 10 seedlings per replication at a density of 148 palms ha⁻¹ on inland soil, covering nearly 60 ha at Bukit Lawang, Kluang, Johor, Malaysia. These trials were planted in 1986. Breeding data covering yield recording, bunch analysis and vegetative measurements of 4467 *dura* palms from 55 populations were analysed for PCA and HCA analyses. The bunch analysis (BA) method, developed by Blaak *et al.* (1963) and improved by Rao *et al.* (1983), was used to estimate the bunch quality traits. Vegetative measurements (VM) and calculations were conducted according



Note: 1 - Binga I; 2 - S. Binga II; 3 - S. Binga III; 4 - Libonas; 5 - Gwenzale; 6 - Gwaka; 7 - Lisala I; 8 - Ndeke; 9 - Mongana; 10 - Bumba; 11 - Lisala II; 12 - Lisala III; 13 - Lisala IV; 14 - Ebonda I; 15 - Ebonda II; 16 - Basoko; 17 - Ligase; 18 - Yahuma; 19 - Lukutu Islands; 20 - Aruwimi; 21 - Kisangani; 22 - Isangi; 23 - Yangambi Station; 24 - Boteka I; 25 - Boteka II; 26 - Boteka III; 27 - Boteka IV; 28 - Boteka V; 29 - Mbanza Ngungu; 30 - Bukayu; 31 - Uvira; 32 - Lusanga I; 33 - Lusanga II; 34 - Tango; 35 - Imbongo; 36 - Kikongo; 37 - Mapangu I; 38 - Mapangu II; 39 - Mapangu III; 40 - Mapangu IV; 41 - Bongimba I; 42 - Bongimba II; 43 - Bongimba III; 44 - Bongimba IV; 45 - Bongimba V; 46 - Matadi; 47 - Tshela I; 48 - Tshela II; 49 - Tshela III; 50 - Lukula; 51 - Kondo I; 52 - Maternie; 53 - Kisantu; 54 - Kondo II; 55 - Gimbe; 56 - Luki.

Figure 1. Collection sites of Zaire oil palm germplasm. Site numbers (in red) show the locations of the corresponding germplasm.

to Corley *et al.* (1971) and Breure and Powell (1988). Yield record (YR) and BA data were recorded from 1990 to 1995. VM were recorded earlier, from 1988 to 1995.

Eighteen phenotypic traits were extracted from an internal MPOB breeding database known as MPOB-Breeding Information System (MPOB-BIS™). These traits include two yield component traits, mean bunch number (MBNO) and, mean bunch weight (MABW); 10 traits of bunch quality components, bunch weight (BWT), mean fruit weight (MFW), mean nut weight (MNW), mesocarp to fruit (MTF), kernel to fruit (KTF), shell to fruit (STF), oil to dry mesocarp (OTDM), fruit to bunch (FTB), oil to bunch (OTB), kernel to bunch (KTB); and six traits of VM, frond production (FP), petiole cross-section (PCS), rachis length (RL), height increment (HI), bunch index (BI) and leaf area index (LAI). The raw data for these 18 traits were analysed using a box plot in the ggplot2 R package to visualise the data distribution of the germplasm. The variables were then standardised to mean 0 and standard deviation 1 before executing the PCA and Ward's HCA using FactoMineR and Factoextra R packages. All analyses were conducted in R ver. 4.1.3 and R studio ver. 2021.09.1.

RESULTS AND DISCUSSION

Performance of Yield, Bunch Quality and Vegetative Traits

Performances of Zaire *dura* germplasm for yield, bunch quality components and vegetative traits were evaluated based on individual palm (Figure 2). The box plots provide a clear visual representation of the data distribution together with its outliers, mean, median and variance in a single concise diagram. ZRE46 produced the highest MBNO, demonstrating the highest number of bunches produced, with a median value of above 15 bunches palm⁻¹ yr⁻¹ (Figure 2a). However, the high MBNO in ZRE46 was not associated with high fresh fruit bunches (FFB) due to its low MABW (Figure 2b). Arolu *et al.* (2017) and Myint *et al.* (2019) suggested that an increase in the number of bunches with moderate bunch weight may boost FFB yields. Among the Zaire germplasm, ZRE03 and ZRE48 produced the highest and lowest MABW, respectively.

Commercial oil palm planting materials typically produce bunches weighing from 10 to 25 kg with 500 to 4000 individual fruits, depending on the bunch size (Corley and Tinker, 2016). The Zaire

germplasm materials demonstrated a moderate bunch weight (BWT) ranging from 5 to 30 kg (Figure 2c). The formation of fruit bunches is influenced by numerous factors including nutrition, water, the supply of carbohydrates, and pollination, such as pollen supply and pollinator activity. Tanya *et al.* (2013) reported that BWT was strongly associated with oil yield. The fruit weight (MFW) involves the weight of three components, *i.e.* the mesocarp, shell and kernel. The MFW of the Zaire populations ranges from 5 to 25 g, with the individual palms of ZRE27 and ZRE40 producing the heaviest fruits (Figure 2d). The MNW of this germplasm ranged from 5 to 8 g, with a particular ZRE40 palm possessing the highest nut weight (>15 g).

ZRE17 exhibited the highest mesocarp to fruit ratio, with a mean MTF of above 50% (Figure 2f). The best individual palm for this trait, however, was found in the ZRE30 population (78%). The mesocarp component contains 95% of palm oil (Corley and Tinker, 2003) and therefore, to cope with the economic trends towards high oil yield, it is important to develop large mesocarp planting materials. Fruits with small kernel and shell sizes generally exhibit an increase in mesocarp content and this will thus enhance oil productivity (Okoye *et al.*, 2009; Shi *et al.*, 2019; Tanya *et al.*, 2013). In line with this, ZRE17 also produced the smallest KTF and KTB, which are components for the kernel trait. The highest KTF (13%) was observed in ZRE15, while the other populations exhibited a KTF median of above 10%, which complies with the KTF criteria for the minimum requirements of *dura* parent selection (5%) in the current Malaysian Standard MS 157:2017 (Department of Standards Malaysia, 2017). The individual palm in ZRE40 mentioned earlier that produced the highest MNW and MFW, was also among the highest in KTF. The ZRE51 population produced the highest KTB, and the highest KTF.

Most of ZRE populations produced oil to dry mesocarp of >75%, with ZRE48 population producing the highest. The highest fruit to bunch ratio was recorded in ZRE35. For both traits, the best individual palm was found in the ZRE40 population (>80%), supported by optimum performances in MFW, MNW, and KTF traits as well. The highest OTB was exhibited by ZRE25 though ZRE28 had an outstanding palm producing 25% oil content. ZRE17 was among the highest in OTB ratios, which are above 15% and this is also associated with the production of high MTF and OTB. A population with good quality features is ideal for further selection for breeding programmes, to incorporate traits related to high oil extraction, thus increasing oil yields.

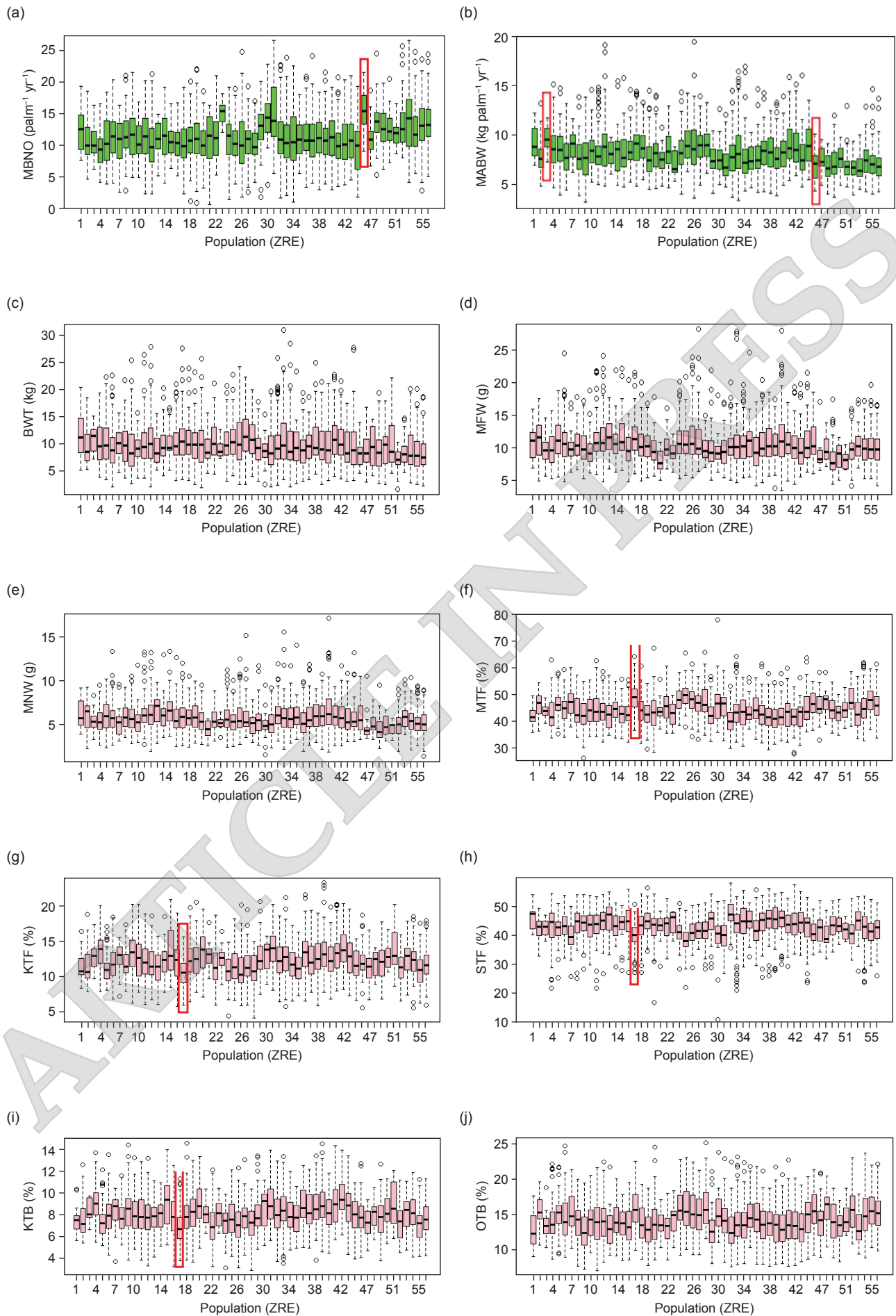
Besides yield and bunch quality components, VM traits also influence the production of palm oil. Populations with desirable vegetative traits are

suitable for introgression with advanced breeding materials. FP has a significant impact on the quantity of bunches as the fruit stalks are joined to each of the axil fronds (Noh *et al.*, 2012). The ZRE populations produced 20 to 28 fronds yr^{-1} , with the highest production observed in ZRE41. In an oil palm breeding program, smaller petiole, shorter rachis length and low HI are desirable vegetative traits (Myint *et al.*, 2019) for the development of compact and dwarf planting materials for higher planting density ha^{-1} (Nor-Azwani *et al.*, 2020). Low HI is a notable factor in oil palm breeding programmes as dwarf palms facilitate easier bunch harvesting and extend the economic lifespan of the palms. ZRE21 exhibited the lowest HI and shortest petiole cross-section (PCS) which is thus ideal for breeding programmes. Meanwhile, ZRE23 exhibited the shortest rachis length which can also be considered a source for the development of compact planting material.

According to the box plot, the kernel and dwarf traits performed well for this germplasm. The trial means of KTF and KTB in the MPOB-Zaire germplasm were 12.21% and 8.01%, respectively. This was higher than the average value of 6.51% and 4.18% in the Dx D palm (Trial 0.332), which was the mother palm used in the development of the Dx P palm in Malaysia (MPOB, Unpublished Data). While the dwarf population, ZRE21, with the HI of 28.12 cm yr^{-1} , was in range with the dwarf oil palm planting materials (26.0 to 32.5 cm yr^{-1}), which was 57.33% shorter than commercial oil palm planting materials (Arolu *et al.*, 2017).

Principal Component Analysis

Principal Component Analysis (PCA), a reduction variables technique results in sturdy patterns of a dataset, which assists plant breeders in exploring and discovering intriguing traits for future breeding programmes. In PCA, eigenvalues of >1.0 is recommended as a general guideline to retain the important components (Iezzoni and Pritts, 1991). The proportion of variance accounted for in individual principal components (PC) can also be adopted as a standard for targeted PC (Ahmadizadeh and Felenji, 2011). Five paramount PC (PC1-PC5) with eigenvalues >1.0 computed 82.69% of the total variability in the 55 MPOB-Zaire oil palm germplasm populations (Table 1). The variances for the PC imply that PC1, PC2, and PC3 correspond to approximately 13 individual variables. Therefore, the variables from PC1 to PC3 need to be prioritised for further Zaire germplasm conservation and breeding programmes. As expected, PC4 and PC5 have smaller eigenvalues of 1.70 to 1.18 with variabilities of 9.44% and 6.55% respectively, equivalent to a single variable, and are only relevant if it has any biological significance.



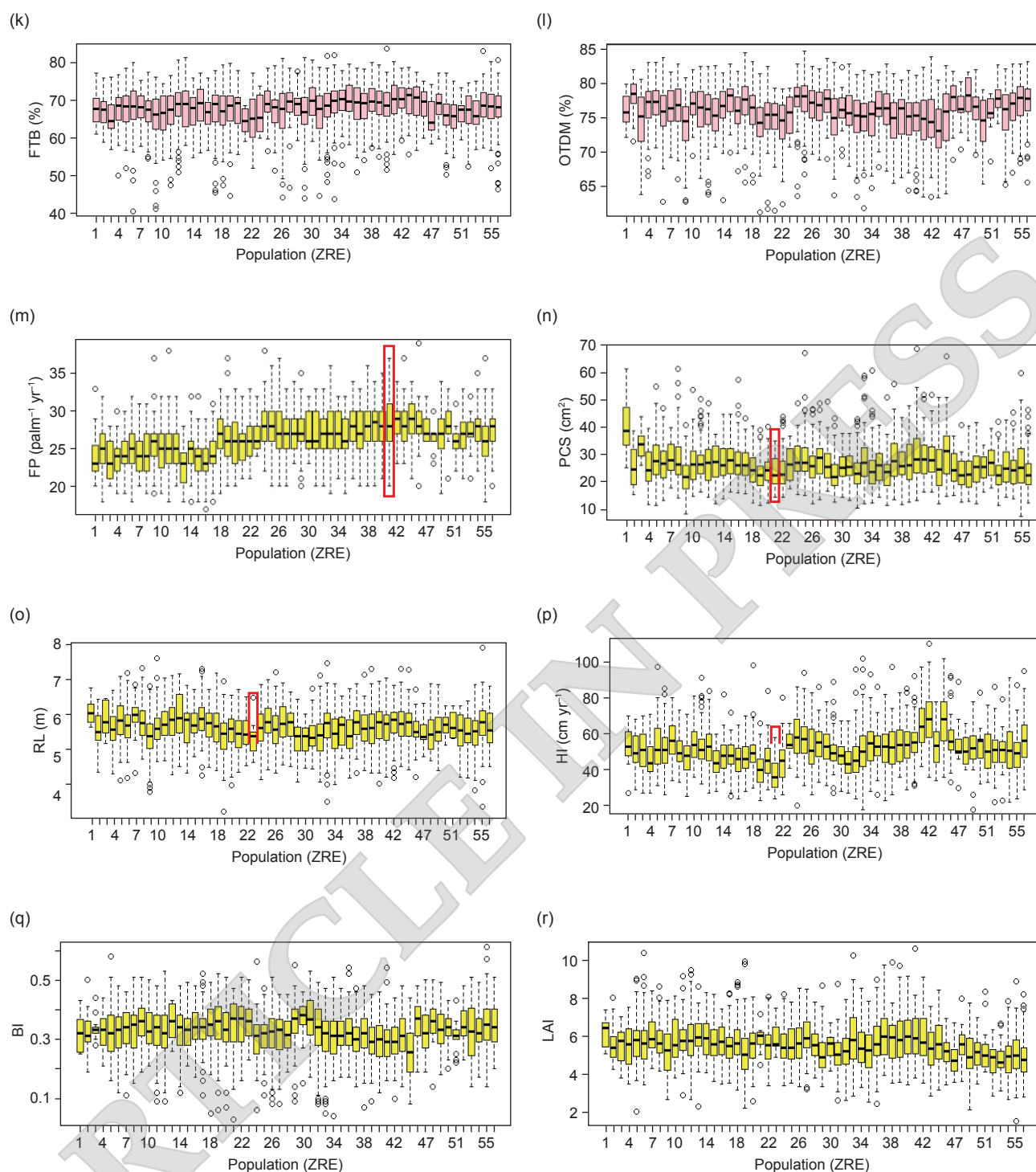


Figure 2. Box plots of the 55 Zaire oil palm populations for each of the 18 traits. (a) Mean bunch number (MBNO), (b) mean bunch weight (MABW), (c) bunch weight (BWT), (d) mean fruit weight (MFW), (e) mean nut weight (MNW), (f) mesocarp to fruit (MTF), (g) kernel to fruit (KTF), (h) shell to fruit (STF), (i) oil to dry mesocarp (OTDM), (j) fruit to bunch (FTB), (k) oil to bunch (OTB), (l) kernel to bunch (KTb), (m) frond production (FP), (n) petiole cross-section (PCS), (o) rachis length (RL), (p) height increment (HI), (q) bunch index (BI), and (r) leaf area index (LAI).

TABLE 1. PRINCIPAL COMPONENTS WITH EIGENVALUES >1.0

Principal components	PC1	PC2	PC3	PC4	PC5
Eigenvalue	5.45	4.14	2.41	1.70	1.18
Variance (%)	30.30	23.03	13.37	9.44	6.55
Cumulative variance (%)	30.30	53.33	66.70	76.14	82.69

PC1 is contributed mainly by MABW (0.812), LAI (0.779), BWT (0.767), PCS (0.723), MNW (0.701), MBNO (-0.695) and RL (0.690) (Figure 3). PC2 is influenced by bunch yield components such as OTB (0.883), MTF (0.873), OTDM (0.802), KTF (-0.749), KTB (-0.685) and STF (-0.677). The positive or negative coefficient values in the PC explained the interpretation of variability in oil palm breeding germplasm (Ahmad *et al.*, 2014).

The ordination of the overlapping pattern showed strong intra-variable correlations, such as that between MBNO and BI (Figure 4a). The right and left quadrants of the plot may also contain the factors responsible for the majority of the variations. Positive correlations exist between variables plotted on the same PC and which are located relatively close together, suggesting that an increase in one causes an increase in the other. An increase in one variable is associated with a decrease in another when the variables are plotted at opposite ends of the plot, indicating negative correlations. MTF, OTDM and OTB traits were negatively correlated with KTF, KTB and STF traits. This suggests that mesocarp content was influenced by the kernel and shell sizes, which was reported by (Shi *et al.*, 2019), and was subsequently reflected in the oil yield production. Figure 4b represents the score plot in a

map of the distribution of 55 Zaire populations. The ZRE populations that are located close to each other on the bi-plot have similar traits and performance profiles, whereas those far from each other are dissimilar. ZRE17, ZRE24, ZRE25, ZRE26, and ZRE28 are located close together in the Q1 quadrant, suggesting similarities in the performance of MTF, OTB and OTDM traits. These five ZRE populations were also located around Boteka, Zaire, where this village is noted for its abandoned oil palm plantations (Jennifer, 2020). ZRE10 is located close to the centre (origin) of the plot, suggesting its performance is average for all the traits studied.

The bi-plot allows visualisation of the combination of both loading vectors (variables) and the PC scores (Zaire populations) in a single plot (Figure 4c). The angles between vectors of different variables demonstrate the correlation in the plot. Firincioglu *et al.* (2009) reported that this diagram can be used to verify populations with interesting trait combinations that might be valuable in a breeding programme. From the bi-plot, ZRE21 was located at the opposite angle to the HI trait, indicating a high negative correlation, which suggests that this population possesses dwarf feature that could be used to develop a shorter oil palm. One of the main goals in oil palm breeding is to reduce the HI to

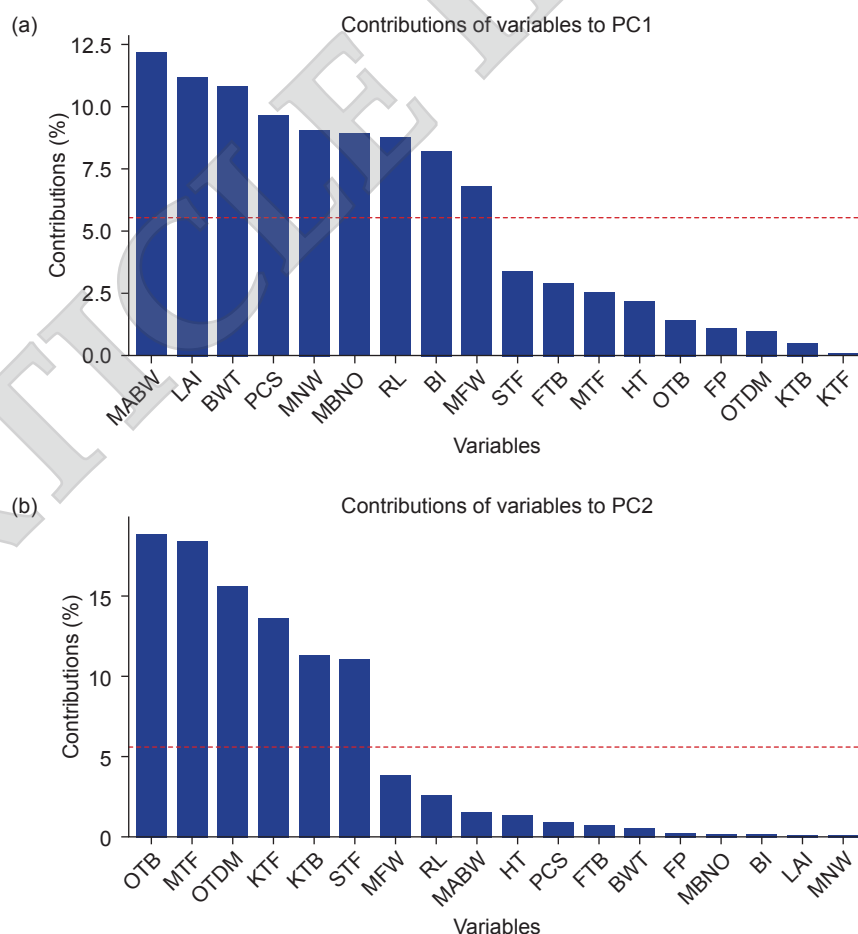


Figure 3. Contribution of variables to (a) PC1, and (b) PC2.

30 cm yr⁻¹ compared to 40 to 70 cm yr⁻¹ in current planting materials (Kushairi *et al.*, 2011; Rajanaidu *et al.*, 2000). One of the approaches to reach this goal is to introgress the height trait from germplasm samples into commercial planting materials (Ong *et al.*, 2018). Aside from that, this ZRE21 population shows good performance in KTF and KTB traits, indicating a favourable association to develop novel breeding material. Those traits are promising for breeding oil palms with high kernel content which could be important sources of lauric acids for the oleochemical industry (Jalani *et al.*, 2003). Population ZRE01 appears to be an outlier and has the strongest positive association with variables in PC1, such as BWT, LAI, and MNW. However, the fact that this population was plotted at an angle greater than 90° between the OTB, MTF, and OTDM implies that there is no association with these economic features. On the other hand, ZRE17 showed the strongest positive association with the traits in PC2, suggesting that this population could be a source of breeding material for yield improvement of the Zaire germplasm.

Cluster Analysis

Clustering methods are used as a complementary analytical task to PCA. The ZRE populations were classified according to the variables associated with each cluster using Ward's clustering method based on Euclidean distance. A dendrogram is formed by the levels of similarity at which the observations are merged, which gives a visual summary of the clustering process and depicts an image of the clusters and their proximity with a sharp reduction in the dimensionality of the original data (Shrestha and Kazama, 2007). Two major clusters were observed for the 55 ZRE populations with a coefficient of 15 (Figure 5). Cluster 1, which is the larger cluster, comprised 34 populations, which was divided into two sub-clusters. Cluster 2 comprised 21 populations. This clustering is in accordance with the PCA bi-plot, whereby Cluster 1 is made up of the combination of the variables in quadrants Q1 and Q4 and is positively associated with PC1. As ZRE01 is an outlier in the bi-plot, it was placed as a singleton

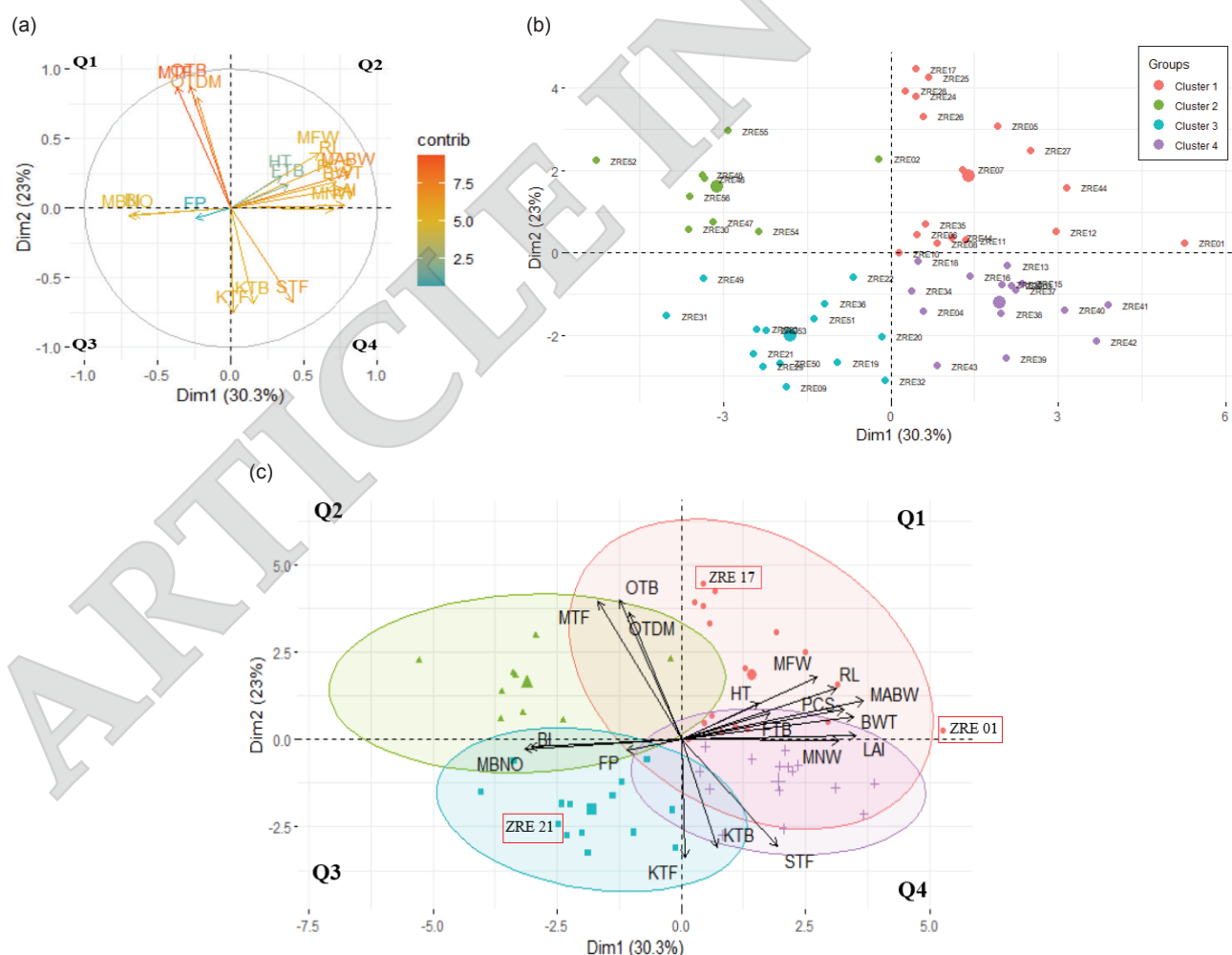


Figure 4. (a) Variables loaded into PC1 and PC2. (b) Distribution of the Zaire populations on a score plot of the first two PCs, indicative of the relationships between the populations. (c) PCA bi-plot showing both the loadings of the 18 trait variables and the PC scores of 55 populations. Vectors with parallel variables to the PC axis have a higher direct contribution to the PC, with small angles indicating a high positive correlation.

in the subcluster. Cluster 2 however, is associated favourably with PC2 and is built by the combination of variables from quadrants Q2 and Q3.

For the development of core collections, populations in the same cluster can be minimised in a regeneration scheme, thus the repetitive genetic materials could be reduced. By providing a working collection representing the entire range of variability, the core collection can play a significant role in the design of new cultivars (Singh, 2009). The fact that unique genes do not necessarily need to be a part of the core collection is well known. Thus, if it is present by chance, the gene ought to be directly added to the sample core set (Mahajan *et al.*, 1996). The ability to identify desirable traits for oil palm improvement could be achieved by providing a core collection with no redundancy, and accurate information for each accession (Frankel, 1984). Thus, the amount of land required for planting and field maintenance costs for an *ex-situ* core collection can be reduced. This study also revealed the ability of morphological traits to assess the genetic diversity of crop populations. This genetic divergence analysis is vital for selecting highly diverse genotypes for a breeding program. As ZRE01 has a greater genetic distance to ZRE46, a cross between both populations will assist in obtaining the maximum genetic divergence of this germplasm.

Both clusters appeared to be comparable based on the performance of several phenotypic traits (Table 2). Some economic features, such as KTF (12%), KTB (8%) and OTDM (76%) appear to be promising for introgression with advanced breeding material. The KTF and KTB values for Zaire germplasm were equivalent to the Nigerian (*dura*) germplasm, but higher than Angola (*dura*) which features 11% KTF and 7% KTB (Rajanaidu *et al.*, 2017). Upon the introduction of the pollinating weevil *Elaeidobius kamerunicus* to Malaysia, the KTB rose from 5% to 7% (Rajanaidu *et al.*, 1996). As a result, the net gain of palm oil is directly impacted by the rise in KTB. Therefore, as proposed by Myint *et al.* (2019), the development of breeding material with high KTB yields will boost large economic returns. In addition, the average HI for both clusters were 39 and 37 cm yr⁻¹, which demonstrated dwarfism prospects. This is about 63% shorter than the 45-75 cm yr⁻¹ in current oil palm planting materials (Arolu *et al.*, 2017). This value is also lower than several other *dura* germplasms such as Angola (42.65 cm), Senegal (46.76 cm), Gambia (43.74 cm) and Sierra Leone (42.30 cm) (Rajanaidu *et al.*, 2017).

Clustering of the majority of the populations appeared to be influenced by their geographical locations (Figure 6). However, several populations from Cluster 2 did not appear associated with geographical factors possibly as a consequence of intensive human activity originating in the Congo

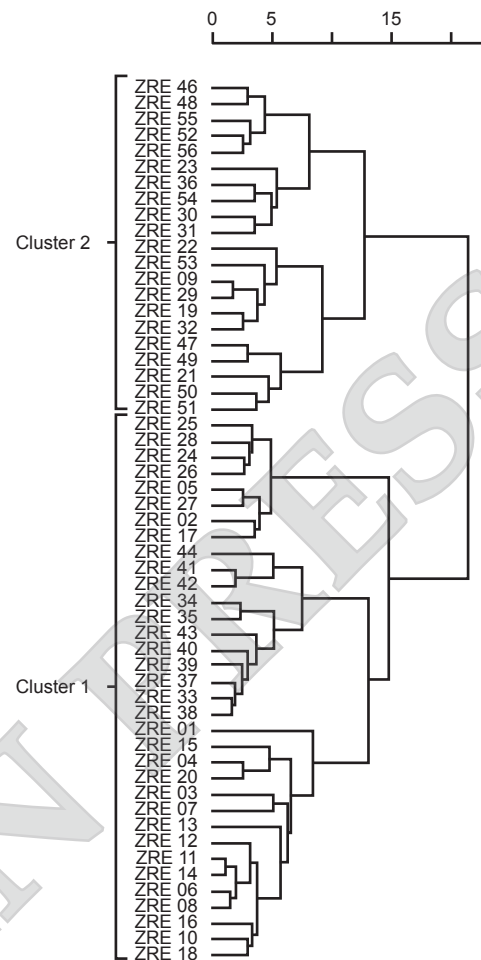


Figure 5. An agglomerative hierarchical cluster dendrogram constructed using the 55 populations, ZRE01 to ZRE55. Populations for the corresponding sample clusters have their initial pairings. Progression through the hierarchy places paired populations into appropriate sample clusters.

Basin, along the Zaire River (Choong *et al.*, 1996). Human intervention in natural habitats can lead to an increase in the level of genetic diversity. Furthermore, as populations used in this study covered the entire geographic range from the rainy to the dry areas, considerable genetic diversity across oil palm populations may be related mainly to geographical differences. ZRE30 and ZRE31 germplasms exhibit low genetic variation due to geographic and climatic factors (Choong *et al.*, 1996). Those populations were located at the edge of the palm belt, and it is assumed that diversity of a species decreases outward from its centre of diversity. The high genetic variability in Zaire germplasm suggested that this germplasm can potentially be a genetic source for oil palm improvement (Zulkifli *et al.*, 2012). Based on multivariate analysis, in conjunction with more advanced molecular tools, the use of the MPOB-Zaire germplasm in breeding and regeneration programmes could be properly strategised.

TABLE 2. CLUSTERS AND MEAN VALUES OF PHENOTYPIC FEATURES

Cluster	MBNO	MABW	BWT	MFW	MNW	MTF	KTF	STF	OTDM
1	9.87	10.64	10.28	10.67	5.91	44.57	12.16	43.26	75.90
2	11.98	9.19	9.02	9.53	5.26	44.95	12.41	42.64	75.79
Cluster	FTB	OTB	KTB	FP	PCS	RL	HI	BI	LAI
1	68.11	14.30	8.04	25.91	27.66	5.69	39.48	0.31	5.71
2	66.95	14.23	8.01	26.94	24.54	5.47	37.21	0.34	5.21

Note: MBNO - Mean bunch number (bunch palm⁻¹ yr⁻¹); MABW - Mean average bunch weight (kg palm⁻¹ yr⁻¹); BWT - Bunch weight (kg); MFW - Mean fruit weight (g); MNW - Mean nut weight (g); MTF - Mesocarp to fruit (%); KTF - Kernel to fruit (%); STF - Shell to fruit (%); OTDM - Oil to dry mesocarp (%); FTB - Fruit to bunch (%); OTB - Oil to bunch (%); KTB - Kernel to bunch (%); FP - Frond production; PCS - Petiole cross section (cm²); RL - Rachis length (m); HI - Height increment (cm); BI - bunch index; LAI - leaf area index.

CONCLUSION

This study successfully characterised 55 populations of the Zaire oil palm germplasm with 18 traits for yield components, bunch quality components and VM using multivariate analysis. PCA revealed possible economic traits in this germplasm, i.e. MABW, BWT, OTB and MTF, that can be used as material for breeding programmes. ZRE21 germplasm can potentially be used in the development of planting materials with dwarf palm and high kernel components. The findings of the PCA are in accordance with the CA constructed. The Zaire populations grouped into two major clusters which appear to be strongly associated with their geographical origins. The information from this study can greatly assist oil palm breeders by allowing systematic management to be implemented in breeding and conservation strategies. Optimum efficiency in core collection of germplasm could be obtained by integrating these results with molecular genotyping information.

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