

Assesment of the Acidity of Progenies From Crosses Between Double Self-fertilized DA 115 D AF AF \times LM 2 T AF AF Oil Palm (*Elaeis guineensis* Jacq) Progenitors in Côte d'Ivoire

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Abstract

Crude palm oil, extracted from the mesocarp of the fruit of the oil palm (*Elaeis guineensis* Jacq.), is the world's most widely produced and consumed vegetable oil. However, the food quality of this oil is influenced by its acidification and the negative effects associated with this acidity. Recent work on progenies from the DA 115 D of the Deli population and LM 2 T of the La Mé population involved in seed production has shown variability in oil acidity within and between these progenies, suggesting the possibility of selection to improve palm oil quality in these progenies. To improve the quality of the oil produced in Côte d'Ivoire, progeny from crosses between double self-fertilized progenitors of DA 115 D and LM 2 T origins were evaluated. The acidity of these progenies was determined using the near infrared spectrometer (NIR). The results showed that 4 progenies were homogeneous with low acidities (acidity < 5%) and 9 progenies were heterogeneous with low and medium acidities (5% < acidity < 10%). In addition, only offspring from combinations involving LM 2509 D AF were homogeneous. As a result, the average acidity of each progeny was all below 5%.

Keywords: Acidity, double self-pollination, oil palm, Côte d'Ivoire

1. Introduction

The oil palm (*Elaeis guineensis* Jacq.) is a perennial monocotyledonous crop in the Arecaceae family. It is allogamous and diploid. Within this *E. guineensis* species, palms are classified into three varietal types based on fruit shell thickness and governed by a single co-dominant shell (sh) gene. The *dura* type (D) is homozygous (sh⁺ sh⁺) for the gene and has a shell thickness of over 2 mm. The *pisifera* (P) type is also homozygous (sh⁻ sh⁻) for the gene, but is characterized by an absence of shell. The *tenera* (T) type is a hybrid between the *dura* and *pisifera* types. It is therefore heterozygous (sh⁺ sh⁻) and its shell thickness is less than 2 mm. *Tenera* is the recommended planting material for oil palm plantations, as its palm oil extraction rate is around 30% (Hartley 1988; Bakoumé 2016).

This plant is cultivated mainly for the two types of the oil it produces: palm oil and palm kernel oil (Bessou & Rival, 2020). Palm oil, extracted from the fruit's mesocarp, is the world's most widely produced and consumed vegetable oil. Global production is estimated at around 79.46 million tons in 2023 (United States Department of Agriculture [USDA], 2023).

However, the food quality of this oil is influenced by the level of ripeness of the fruit, and the conditions under which the oil is extracted and stored can lead to increased acidity and rancidity of the oil (Domonhédou et al., 2018).

Recent studies on palm oil acidity have identified an endogenous lipase expressed in the fruit mesocarp. This lipase, controlled mainly by a major FLL1 gene and two other minor genes, degrades triglycerides by releasing

free fatty acids, thus causing palm oil acidity (Sambanthamurthi et al., 2000; Nurniwalis, et al., 2007; Nurniwalis et al., 2008, 2015; Ngando Ebongue et al., 2008; Tranbarger, Dussert & Joe 2011; Morcillo et al., 2013; Domonh do et al., 2018).

In *E guineensis*, varietal improvement is based on a reciprocal recurrent selection (RRS) scheme. This scheme exploits the heterosis effect existing between two population groups (A and B) with complementary characteristics (Meunier & Gascon, 1972). Group A, made up of *dura* palms of Asian (Deli) and Angolan origin, is characterized by a small number of large bunches (Adon et al., 2021a). Group B is made up of *pisifera* and *tenera* palms producing a large number of small bunches from different African origins including La M  (C te d'Ivoire) (Noumouha, 2015 ; Adon et al., 2021a).

Breeding work to reduce the acidification of palm oil has identified both high-acid and low-acid genotypes in the genetic background of DA 115 D belonging to group A of the RRS. The same applies to the LM 2 T genetic background belonging to group B (Ngando Ebongue et al., 2008; Cadena et al., 2012; Wong, et al., 2015; Likeng-Li-Ngue et al., 2016; Domonh do et al., 2017).

In order to improve the quality of the oil produced by these two origins involved in seed production currently in C te d'Ivoire, crosses have been made between certain homozygous low-acid or heterozygous double self-pollinated DA 115 D AF AF \times LM 2 T AF AF progenitors. The aim of the present study is therefore to assess the acidity of the palm oil produced by the progenies from these crosses, in order to select genitors producing low-acidity oils for use in oil palm seed production in C te d'Ivoire.

2. Materials and Methods

2.1 Study Site

The progenies were planted on plots C9/1 and D9/4 in 2005 at Ehania / PALMCI (5 19' N; 2 46' W; 12 m) located in the humid tropical zone of Aboisso department in south-eastern C te d'Ivoire. This zone is characterized by a bimodal rainfall regime with two rainy and two dry seasons. Annual rainfall varies from 1,700 to 2,200 mm, with 1,800 hours of sunshine and an annual temperature ranging from 22 to 31  C. Soils in this region are ferrallitic, with a texture composed mainly of clay and sand. The pH ranges from 4.5 to 7 (Kablan, 2020; Adon et al., 2021b; Soumahoro et al., 2023).

2.2 Plant Material

The study involved 239 oil palms from 13 progenies resulting from crosses of DA 115 D AF AF \times LM 2 T AF AF origins (Table 1). These crosses were made between 12 *dura* (Deli) progenitors and 7 self-fertilized *pisifera* (La M ) progenitors used in seed production and retained for the second cycle. In other words, the *dura* parents of our progenies are DA 115 D AF AF types (double self-fertilization), with DA 115 D AF grandparents (single self-fertilization) and DA 115 D ancestors. *Pisifera* parents are LM 2 T AF AF (double self-fertilization), grandparents LM 2 T AF (self-fertilization) and LM 2 T ascendants.

2.3 Methods

2.3.1 Bunch Harvesting and Oil Extraction

Ripe and fresh bunches of 1 to 5 detached fruits from all producing palms were harvested and erupted. A sample of 100 ripe fruits from each progeny was then taken and cooked in an autoclave at 2 bar pressure. After cooking, the oil was extracted using a manual press, packaged in pillboxes and heated in an oven at 100  C for 1 hour.

2.3.2 Determination of Palm Oil Acidity

For the determination of acidity, 1 ml of oil was taken from the oils packaged in pillboxes and placed in small 8 mm diameter glass tubes. These tubes were preheated on a hot plate at 60  C for 15 min and then run on a near infrared spectrometer (NIR) coupled to OPUS/LAB version 2015 software (Che & Mirghani, 2000). It should be noted that we preferred to use NIR to determine the acidity of our oils rather than conventional chemical methods, because of its ability to measure several oil quality control parameters in a fraction of the time. It contains no chemicals and can measure up to one hundred samples per day, all within commercial specifications (Che & Moh, 1998).

The different acidity classes were defined as described by Likeng-Li-Ngue et al. (2020):

- Low acidity: acidity below 5%;
- Medium acidity: acidity between 5 and 10%;
- High acidity: acidity greater than 10%.

2.3.3 Data Analysis

The Lilliefors test was performed to test the normality of the measured variable. Next, analyses of variance (ANOVA) were performed to check whether the mean acidity observed was different within intra-origin progenies. Also, the t-test and Tukey's test were used to compare the means of intra-origin progenies. In addition, hierarchical ascending classification (HAC) was used to assess the acidity structure of the progenies. All these analyses were carried out using XLSTAT version 19 software, and histograms were produced using Microsoft Excel 2013.

Table 1. Progenies and their genetic origins

Origins	Genetic crosses	No	Progenies
LM 2509 D AF × LM 3387 T AF	LM 7120 D × LM 12426 P	1	LM 25767
	LM 7106 D × LM 13534 P	2	LM 25772
	LM 10374 D × LM 13545 P	3	LM 25769
LM 2523 D AF × LM 3387 T AF	LM 10374 D × LM 13545 P	4	LM 25771
	LM 10357 D × LM 12417 P	5	LM 25757
LM 2523 D AF × LM 2453 T AF	LM 10390 D × LM 13539 P	6	LM 25761
	LM 10448 D × LM 13534 P	7	LM 25760
LM 3005 D AF × LM 3387 T AF	LM 10440 D × LM 12417 P	8	LM 25763
	LM 10455 D × LM 13535 P	9	LM 25753
LM 2515 D AF × LM 3390 T AF	LM 6731 D × LM 12668 P	10	LM 25765
	LM 7651 D × LM 12417 P	11	LM 25770
LM 2515 D AF × LM 3387 T AF	LM 7655 D × LM 13545 P	12	LM 25766
	LM 6725 D × LM 13534 P	13	LM 25759

3. Results

3.1 Evaluation of Individual Values for Each Progeny

The average acidity of the progenies was 3.07%, with a coefficient of variation of 65.53% (Table 2).

The individual values of the progenies showed the existence of two acidity classes (Figures 1 and 2). The first class corresponds to individuals with low acidity (acidity < 5%) and the second class to those with medium acidity (5% < acidity < 10%). Out of a total of 239 palms assessed, 206 showed low acidity and only 33 medium acidity. The individual values of progenies LM 25763, LM 25765, LM 25766 and LM 25767 all showed low acidities ranging from 0.37 to 4.96% (Figure 1). As for the individual values of the other progenies, they produced both low-acidity oils and average acidities ranging from 0.36 to 10.06% (Figure 2). In addition, the male progenitors LM 12417 P, LM 13545 P and LM 13534 P involved in several crosses produced both low-acid and medium-acid offspring.

3.2 Intra Origin Progenies

The Lilliefors test ($D = 0.052$; $p\text{-value} = 0.123$) showed that the data distribution followed a normal distribution.

Analyses of variance performed on the data showed that there were significant and non-significant differences within intra-origin descendants (Table 3).

The t-test applied to data from LM 25767 and LM 25772 intra-origin progenies from the LM 2509 D AF × LM 3387 T AF combination showed that they produced statistically identical acidities of 2.08 and 1.91% respectively (Table III). The same was true of the LM 25753, LM 25760 and LM 25763 intra-origin progenies of the LM 3005 D AF × LM 3387 T AF combination, with statistically identical acidity values of 3.45%, 3.872% and 2.75% respectively (Table 3). Within-origin progenies of the LM 2515 D AF × LM 3387 T AF and LM 2523 D AF × LM 3387 T AF combinations produced different acidities within each combination (Table 3).

3.3 Structuring the Progenies

Hierarchical ascending classification (HAC) applied to the average acidity of the different progenies enabled them to be grouped into three homogeneous classes (Figure 3). The results of the analysis of variance reported in Table 4 showed significant differences between the classes. Class 1, made up of progenies LM 25757, LM 25760,

LM 25761 and LM 25770, and showed the highest acidity percentages, with a value of 4.41%. Class 3, comprising progenies LM 25765, LM 25767 and LM 25772, was made up of low-acidity individuals with a value of 1.98%. Class 2, representing the other progenies, was intermediate between the other two classes.

Table 2. Overall acidity performance of progenies

Variable	Minimum	Maximum	Average	Standard deviation	CV
Acidity (%)	0.36	10.06	3.072	2.005	65.526

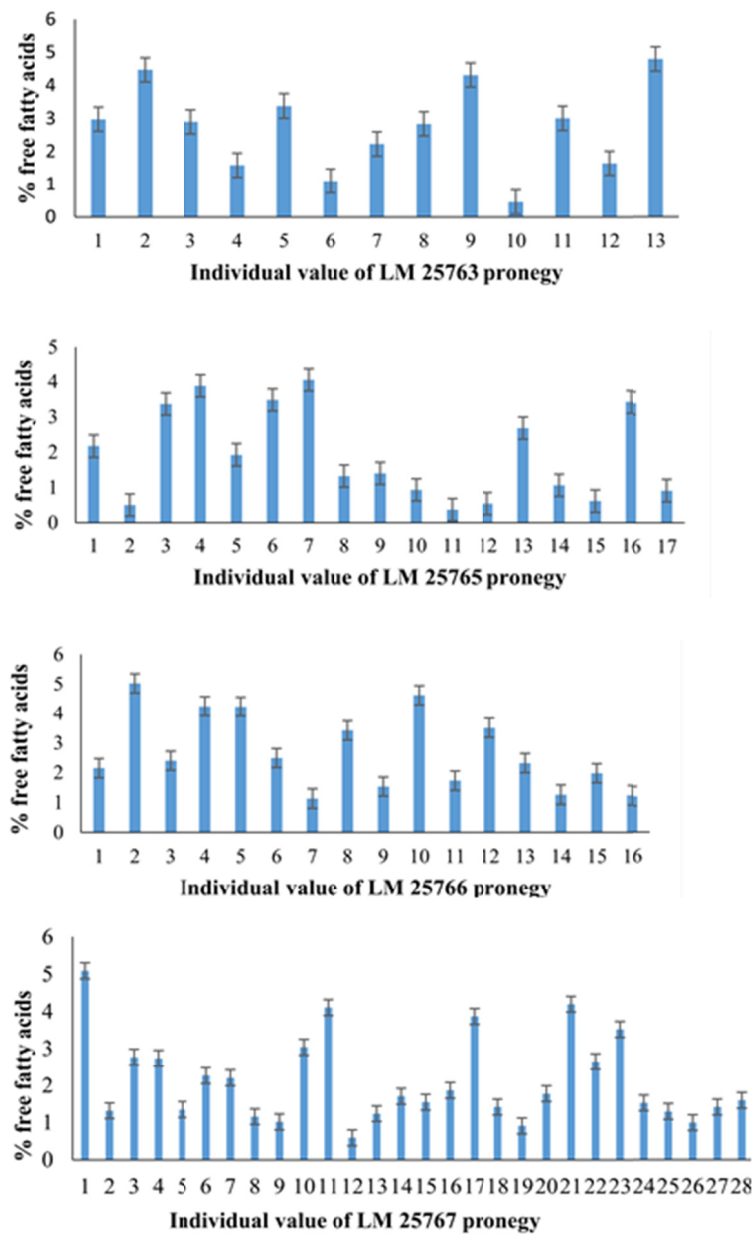


Figure 1. Progenies producing low acidity

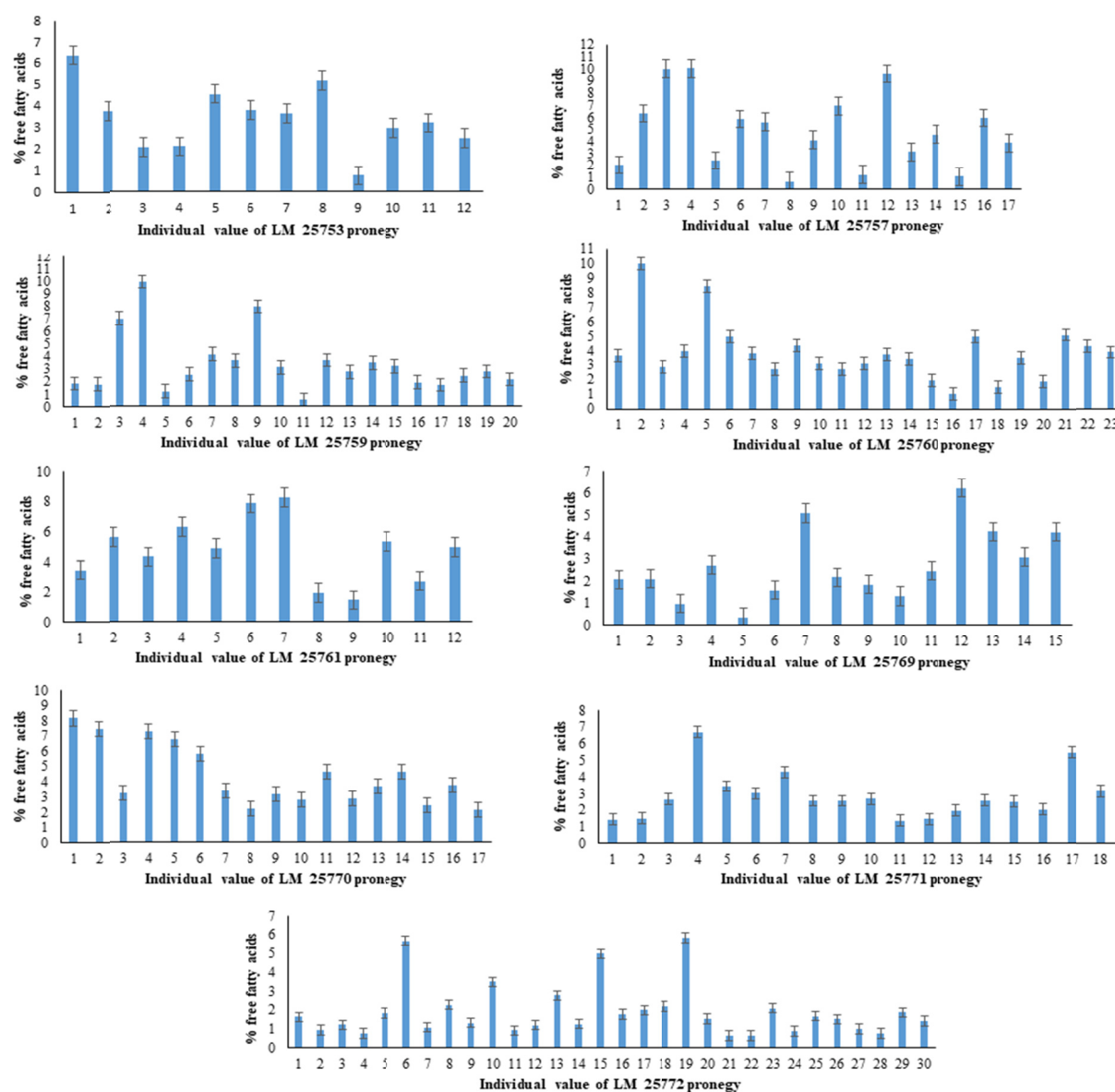


Figure 2. Progenies producing medium acidity

Table 3. Comparison of average acidity values of intra-origin progenies

Genetic Origins	Crosses	Progenies	Acidity (%)	Parametric tests
LM 2509 D AF × LM 3387 T AF	LM 7120 D × LM 12426 P	LM 25767	2.08±1.12 ^a	T-test t = 0.60; p = 0.60
	LM 7106 D × LM 13534 P	LM 25772	1.91±1.36 ^a	
	LM 10455 D × LM 13535 P	LM 25753	3.45±1.46 ^a	
LM 3005 D AF × LM 3387 T AF	LM 10448 D × LM 13534 P	LM 25760	3.87±1.98 ^a	One-factor ANOVA F = 1.73; p = 0.19
	LM 10440 D × LM 12417 P	LM 25763	2.75±1.27 ^a	
	LM 6725 D × LM 13534 P	LM 25759	3.38±2.31 ^{ab}	
LM 2515 D AF × LM 3387 T AF	LM 7655 D × LM 13545 P	LM 25766	2.70±1.25 ^b	One-factor ANOVA F = 3.50; p = 0.04
	LM 7651 D × LM 12417 P	LM 25770	4.38±1.93 ^a	
	LM 10357 D × LM 12417 P	LM 25757	4.91±2.96 ^a	
LM 2523 D AF × LM 3387 T AF	LM 10374 D × LM 13545 P	LM 25769	2.7±1.56 ^b	One-factor ANOVA F = 5.42; p = 0.007
	LM 10374 D × LM 13545 P	LM 25771	2.86±1.38 ^b	

Note. Offspring whose averages followed by the same letter are not statistically different.

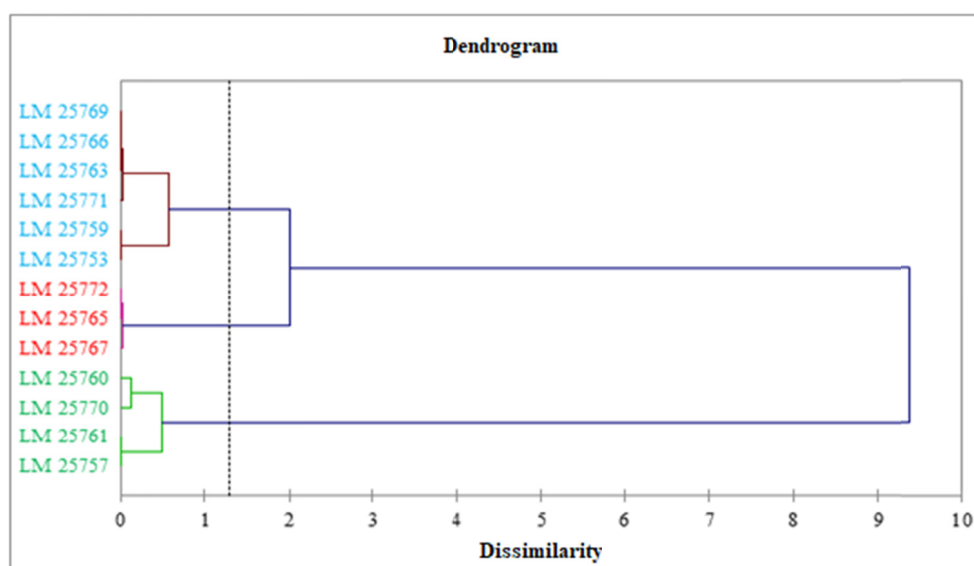


Figure 3. Three homogeneous classes grouped by HAC applied to the average acidity of the different progenies

Table 4. Main characteristics of classes formed by hierarchical ascending classification

Variable	Class 1 (N = 4)	Class 2 (N = 6)	Class 3 (N = 3)	One-factor ANOVA
Acidity (%)	4.41±2.3 ^a	2.98±1.65 ^b	1.98±1.25 ^c	F = 34.15; p < 0.0001

4. Discussion

The study of palm oil acidity in progenies from DA 115 D AF AF × LM 2 T AF AF crosses showed great variability within each progeny on the one hand, and between each progeny on the other. The individual values of these progenies showed that 4 progenies were homogeneous with low acidities and 9 were heterogeneous with low and medium acidities. In addition, the average acidities of the progenies were all below 5%. These results could be explained by the fact that these progenies inherited the genes responsible for low acidity from homozygous or low-acid oil-producing progenitors. Our results corroborate those obtained by Likeng-Li-Ngue et al. (2016). According to these authors, an offspring is homogeneous with low acidity if both parents have a genotype producing low-acid oil. On the other hand, it is heterogeneous if and only if at least one of the two parents is heterozygous for low acidity. However, our results differ from Likeng-Li-Ngue et al. (2020). In their study, these authors obtained only homogeneous progenies with high acidity or heterogeneous progenies.

Evaluation of the male progenitors involved in several crosses showed that these progenitors were heterogeneous, with low and medium acidities. These results could be explained by the fact that these broodstock from the LM 3387 T AF genetic origin are heterozygous and have transmitted this gene to their offspring.

In addition, intra-origin progeny comparisons showed that progeny from combinations involving the LM 2509 D AF and LM 3005 D AF origins were homogeneous. As for the structuring of progenies carried out by HAC, only progenies from combinations involving the LM 2509 D AF origin were homogeneous. As a result, only LM 2509 D AF was homogeneous with low acidity, and LM 3005 D AF, LM 2515 D AF, LM 2523 D AF and LM 3387 T AF were heterogeneous. These results show that the acidity of palm oil depends on genotype, type of cross and genetic origin. Indeed, our results are in agreement with those obtained by Domonhédou et al. (2017); Morcillo et al. (2013); Likeng-Li-Ngue et al. (2016). As these authors' studies were conducted on the DA 115 D origin, they concluded that the LM 2509 D AF progenitor obtained in the second generation was homozygous with low acidity and the LM 2515 D AF, LM 2523 D AF progenitors were heterozygous. Domonhédou et al. (2017) also identified within the LM 2 T origin in the second generation some homozygous genitors with low acidity and others heterozygous.

The results obtained in this study show that from crosses made between second-generation progenitors of DA 115 D and LM 2 T origins heterozygous with low and high acidity, that it is possible to obtain offspring producing oils with low acidity < 5% as recommended by Codex Alimentarius (2015).

5. Conclusion

Progenies resulting from crosses of some self-pollinated double progenitors used in oil palm seed production in Côte d'Ivoire with DA 115 D and LM 2 T founder progenitors revealed that 4 progenies were homogeneous with low acidities and 9 were heterogeneous with low and medium acidities. Furthermore, taking into account the genetic origins of groups A and B of the reciprocal recurrent selection scheme, only offspring from combinations involving the LM 2509 D AF origin were homogeneous. As a result, the average acidity of each progeny was below 5%.

Taking these results into account in seed production will enable oil palm growers to benefit only from seeds producing low-acid oils.

References

- Adon, B., Bakoumé, C., Konan, J. N., Diabaté, S., Cochard, B., Koutou, A., ... Sokouri, D. P. (2021b). Selection of (Deli × Angola Novo-Redondo) Selfed × La Mé Progenies for Improved Oil Palm Productivity. *Journal of Agricultural Science*, 13(12), 51-60. <https://doi.org/10.5539/jas.v13n12p51>
- Adon, B., Konan, J. N., Cochard, C., Flori, A., Diabaté, S., Bakoumé, C., & Sokouri, D. P. (2021a). Agronomical Performances of Angolan Natural Oil Palm Accessions and Interests for Oil Palm Selection in Côte d'Ivoire. *Journal of Agricultural Science*, 13(11), 64-73. <https://doi.org/10.5539/jas.v13n11p64>
- Bakoumé, C. (2016). Genetic diversity, erosion and conservation in oil palm. In M. R. Ahaja & S. Mohan Jain (Eds.), *Genetic diversity and erosion in plants-Case studies* (pp. 1-31). Springer International Publishing, AL, Zurich. https://doi.org/10.1007/978-3-319-25954-3_1
- Bessou, C., & Rival A. (2020). Palmier à l'huile: l'état des lieux sur la déforestation et les standards de durabilité. *Rapport d'étude pour le CST-Forêt de l'AFD* (p. 101). Montpellier, France.
- Cadena, T., Prada, F., Perea, A., & Hernán, M. R. (2013). Lipase activity, mesocarp oil content, and iodine value in oil palm fruits of *Elaeis guineensis*, *Elaeis oleifera*, and the interspecific hybrid O×G (*E. oleifera* × *E. guineensis*). *J. Sci. Food Agric*, 93, 6741680. <https://doi.org/10.1002/jsfa.5940>
- Che Man Y. B., & Moh M. H. (1998). Determination of free fatty acids in palm oil by near-infrared reflectance spectroscopy. *Journal of the American Oil Chemists' Society*, 75, 557-562. <https://doi.org/10.1007/s11746-998-0065-0>
- Che, Y. M., & Mirghani, M. (2000). Rapid method for determining moisture content in crude palm oil by Fourier transform infrared spectroscopy. *Journal of the American Oil Chemists' Society*, 77, 631-637.
- Codex Alimentarius. (2015). *Norme pour les huiles végétales portant un nom spécifique* (p. 18). CXS 210-1999; Adoptée en 1999. Amendée en 2005, 2011, 2013, 2015, 2019, 2021, 2002. Révision: 2001, 2003, 2009, 2017, 2019.
- Domonhédó, H., Cuéllar, T., Espeout, S., Droc, G., Summo, M., Rivallan, R., ... Billotte, N. (2018). Genomic structure, QTL mapping, and molecular markers of lipase genes responsible for palm oil acidity in the oil palm (*Elaeis guineensis* Jacq.). *Tree Genetics & Genomes*, 14, 1-12. <https://doi.org/10.1007/s11295-018-1284-7>
- Domonhédó, H., Nodichao, L., Billotte, N., Ahanhanzo, C., & Cros, D. (2017). Variabilité génétique et compréhension de la transmission de l'acidité de l'huile dans les fruits mûrs chez le palmier à huile (*E. guineensis*, Jacq.). *J. Appl. Biosci.*, 119, 11871-11887. <https://doi.org/10.4314/jab.v119i1.5>
- Hartley, C. W. S. (1988). *The Oil Palm (Elaeis guineensis Jacq.)*. Scientific and Technical Publication, Longman, New York.
- Kablan, K. A. B. M. (2020). *Fusariose vasculaire du palmier à huile [Elaeis guineensis (Arecaceae)] cultivé en Côte d'Ivoire: Sélection de descendances hybrides tolérantes et identification de marqueurs phénoliques* (Thèse 3^e cycle, p. 170). Université Nangui Abrogoua, Abidjan.
- Likeng-Li-Ngue, B. C., Bell, J. M., Ngando-Ebongue, G. F., Ntsomboh, G. N., & Ngalle H. B. (2016). Genetic determinism of oil acidity among some DELI oil palm (*Elaeis guineensis* Jacq.) progenies. *African J. Biotechnol.*, 15, 184111845. <https://doi.org/10.5897/AJB2016.15461>
- Likeng-Li-Ngue, B. C., Ngalle, B. H., Nsimi, M. A., Ntsomboh, N. G., Limala II, E. P., & Bell, J. M. (2020). Variability of Crude Palm Oil Acidity among Individual Oil Palm (*Elaeis Guineensis* Jacq.) Progenies of La Dibamba Germplasm. *J Agri & Soil Sci.*, 4(2), 000583. <https://doi.org/10.33552/WJASS.2020.04.000583>

- Meunier, J., & Gascon, J. P. (1972). Le schéma de sélection du palmier à huile à l'I.R.H.O. *Oléagineux*, 27, 1-12.
- Morcillo, F., Cros, D., Billotte, N., Ngando-Ebongue, G. F., Domonhédou, H., & Pizot, M. (2013). Improving palm oil quality through identification and mapping of the lipase gene causing oil deterioration. *Nat. Commun.*, 4, 2160. <https://doi.org/10.1038/ncomms3160>
- Ngando Ebongue, G. F., Koonan, P., Nouy, B., Zok, S., Carrière, F., Amvam, Zollo, P. H., ... Arondel, V. (2008). Identification of oil palm breeding lines producing oils with low acid values. *Eur. J. Lipid Sci. Technol.*, 110, 5051509. <https://doi.org/10.1002/ejlt.200700263>
- Noumouha, N. G. (2015). *Évaluation en Côte d'Ivoire des introductions de palmiers à huile (Elaeis guineensis Jacq.) dans le schéma de sélection récurrente réciproque: Cas des populations subspontanées et préalablement sélectionnées du Nigeria et du Cameroun* (Thèse 3e cycle, p. 193). Université Félix Houphouët-Boigny, Abidjan.
- Nurniwalis A. W., Siti Nor Akmar, A., Chan, P. L., & Manaf, M. A., (2007). Isolation of a cDNA encoding a lipase class 3 family protein from oil palm (*Elaeis guineensis* Jacq.). *Proc. PIPOC 2007 Int. Palm Oil Congr. Agriculture, Biotechnol. Sustain.*, 101111020.
- Nurniwalis, A. W., Suhaimi, N., Siti Nor Akmar, A., Aminah, S., & Mohamad Arif, M. A. (2008). Gene discovery via expressed sequence tags from the oil palm (*Elaeis guineensis* Jacq.) mesocarp. *J. Oil Palm Res.*, 2, 87196.
- Nurniwalis, A. W., Zubaidah, R., Siti Nor Akmar, A., Zulkifli, H., Mohamad Arif, M. A., Massawe, F. J., ... Parveez, G. K. A. (2015). Genomic structure and characterization of a lipase class 3 gene and promoter from oil palm. *Biologia Plantarum*, 59, 227-236. <https://doi.org/10.1007/s10535-015-0500-7>
- Sambanthamurthi, R., Rajanaidu, N., & Parman, S. H. (2000). For lipase activity in the oil palm. In J. Harwood & P. J. Quinn (Eds.), *Biochem. Soc. Trans.*, 28, 7691770. <https://doi.org/10.1042/0300-5127:0280769>
- Soumahoro, M., Konan, J. N., Boyé, M. A. D., Niamketchi, G. L., & Fofana, V. P. (2023). Agronomic evaluation of some progenies resulting from crosses between double self-fertilised genitors of Deli and La Mé origins used in oil palm (*Elaeis guineensis* Jacq.) seed production in Côte d'Ivoire. *Int. J. Biol. Sci.*, 17(6), 2194-2205. <https://doi.org/10.4314/ijbcs.v17i6.5>
- Tranbarger, T. J., Dussert, S., & Joe, T. (2011). Regulatory mechanisms underlying oil palm fruit mesocarp maturation, repening, and functional specialization in lipid and carotenoid metabolism. *Plant Physiol.*, 156, 564-584. <https://doi.org/10.1104/pp.111.175141>
- USDA (United States Department of Agriculture). (2023). *Oilseeds: World market and trade* (Circular Series August 2023, pp. 1-41). Foreign Agricultural Service, United States Department of Agriculture. Retrieved from <http://apps.fas.usda.gov/psdonline/circulars/production.pdf>
- Wong, Y. T., Kushairi, A., Rajanaidu, N., Osman, M., & Wickneswari, R. (2015). Screening of wild oil palm (*Elaeis guineensis*) germplasm for lipase activity. *J. Agric. Sci.*, 154, 124111252. <https://doi.org/10.1017/S0021859615001112>

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The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data Sharing Statement

No additional data are available.

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