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Genotypic variability in oil palm (*Elaeis guineensis* Jacq.) towards drought damages in Benin (West Africa)

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ABSTRACT

Oil palm is an important crop largely produced in the world. However, its productivity is highly impaired by drought in Benin (West Africa). This study aimed at identifing the genotypic diversity in the response to drought conditions among ten oil palm genotypes (L1 to L10) in adult stage based on five predefined drought damage traits: number of green broken leaves (NGBL), number of folded leaves (NFL), number of unopened leaves (NUL) number of base leaves dry out (NBLD) and number of trees with central leaf cabbage toppled (NLCT). Principal component analysis (PCA) has shown that NGBL, NFL and NLCT are more relevant for drought study in adult palms trees. PCA has also shown a high variability in genotypes. Thus, L9, L8, L3, L1, L2 and L10 were drought tolerant whereas L7 was drought sensitive. Between these two groups, L5, L6 and L4 display intermediate tolerance to drought. Planting tolerant genotypes is a necessity to avoid drought damage. Consequently, the future research must insight the biochemical and biomolecular bases of tolerance to drought between the ten genotypes.

Keywords: Oil palm, drought sensitivity, drought damages, drought tolerance.

INTRODUCTION

Oil palm (*Elaeis guineensis*; Arecaceae) is a perennial, arborescent, monocotyledonous crop largely produced worldwide due to its economic potential for oil production. The fruit produces two types of oil (red palm oil (RPO) or crude palm oil (CPO) and palm kernel oil (PKO)) widely used in the food industry, cosmetics, medicines, soap and more recently in biodiesel production (Legros et al., 2009; Mba et al., 2015). CPO contains 50% saturated, 40% monounsaturated, 10% polyunsaturated fatty acids and several nutrients such as carotenes, tocopherols, tocotrienols which plays significant roles in human metabolic processes and growth (Kritchevsky, 2000; Obahiagbon, 2012).

Oil palm tree is by far the oleaginous plant that provides the highest oil yield, averaging 4 tonnes ha^{-1} year^{-1} (Corley and Tinker, 2016; Rival and Levang, 2014). The worldwide palm plantations are commonly formed using genotypes of African

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oil palm (*Elaeis guineensis* Jacq.), which are distributed over humid tropical areas, particularly in some equatorial countries of Africa, Asia, and Latin America (Corley and Tinker, 2016). However, oil palm does not withstand severe or even moderate drought spells and, therefore, crop yields are severely constrained under water-limiting conditions (Silva et al., 2016).

In Benin (West Africa) where the oil palm plays an important economic role (Aholoukpè et al., 2013), drought events can occur during the short dry season (August – September) and the long and pronounced dry season (November – March); and the average rainfall is 1,200 mm year^{-1} (Nodichao et al., 2011) whereas optimum annual rainfall for the oil palm to achieve maximum production and yield distributed from 1800 to 3000 mm (Azzeme et al., 2016; Cao et al., 2011; Corley and Tinker, 2003). This annual minimum deficit of 600 mm, confirmed by Adjahossou (1983) explains the low productivity of the Benin palm grove (Nodichao, 2008). When it lasts, the palm begins to show successive vegetative damages such as increasing of unopened leaves (known as spears) number, breaking of green leaves, drying out of all the leaves at the base of the crown, toppling of the central leaf cabbage and death of palm (Maillard et al., 1974). The authors used this drought damages to develop a sensitivity index (SI) that determines the effects of severe drought in an oil palm population using the formula SI = (10M+5S3+3S2+2S1) / N in which (S1) is accumulation stage of five or six spear leaves in the centre of the crown, (S2) is stage of four to six green leaves collapsed or broken, accompanied by drying of fruit bunches, (S3) is stage where all leaves at the base of the crown dried and foliage in the centre of the crown collapsed, (M) is number of dead tree and (N), number of healthy and productive trees.

Abiotic stress tolerance, especially drought, is the alternative trait for oil palm improvement in the next step (Cha-um et al., 2010). Thereby, this study was allowed to observe the behavior of ten oil palm genotypes under drought conditions in field at *Centre de Recherches Agricoles Plantes Pérennes (CRA-PP)* of *Institut National de Recherches Agricoles du Bénin (INRAB)*, in order to analyze the genotypic variability in response to drought, based on the different drought damages, for future insight at biochemical and molecular levels of these traits.

MATERIALS AND METHODS

Experimental site

The study was carried out on the experimental plot POPP01 installed at the CRA-PP research institute of Pobe located at 7°49′58.83″N and 2°13′37.60″E in southeastern Benin. The region is subjected to a subequatorial climate with a short dry season from August to September and a long and pronounced dry season from November to March and 1,200 mm of average yearly rainfall with considerable inter annual variations (Djegui et al., 1992; Nodichao et al., 2011; Gnanguenon et al., 2015). It is considered as marginal for oil palm growing and the water deficit can sometimes reach 750 mm year^{-1} (Nouy et al., 1999). In 2017, an annual rainfall of 1056 mm was recorded at CRA-PP and the pronounced dry season period (November 2017 - March 2018) showed a monthly average rainfall under 50 mm (Figure 1). The soil is of ‘ferrallisol’ type (generally loamy sand) and the loam fraction is mostly kaolinite, goethite and hematite (Djegui et al., 1992). Annual mean air temperature varies between 22 °C and 30 °C and mean evapotranspiration is 3.5 mm d^{-1} (Nodichao et al., 2011).

Plant material and experimental design

Ten (10) oil palm genotypes (hybrid crosses) named L1 to L10, were studied. The genotypes were chosen because of their difference in drought tolerance. The palm trees were planted on May 30 and 31, 1996 on 5.85 hectares with density of 143 plants/ha; thirty trees were planted per elementary plot (6 rows of 5 trees) and cross were repeated in two elementary plot. Thus, a total of sixty trees were observed for each genotype.

Data collection

Data were collected from November 2017 to March 2018 during dry season (Figure 1). Data parameters recorded are number of green broken leaves (NGBL), number of folded leaves (NFL), number of unopened leaves (NUL) number of base leaves dried out (NBLD) and number of trees with central leaf cabbage toppled (NLCT) according to the drought damages described by Maillard et al. (1974).

Statistical analysis

The statistical analyses were performed using R 3.5.1 and XLSTAT 2014.5 software. To assess the drought tolerance of the different genotypes, correlation among drought damages traits was estimated by Pearson's method at significance level of $p < 0.05$ using the "corrplot" package of R software and clustering was performed. The principal component analysis (PCA) was performed with XLSTAT and PCA ranking value was used to assess the drought tolerance of different genotypes, based on the formula described by Dossa et al. (2017):

PCA score value = (contribution of F1 (%) x F1) + (contribution of F2 (%) x F2) + (contribution of F3 (%) x F3).

To investigate the behavior of the ten genotypes toward drought stress obtained by PCA, sensibility index (SI) of Maillard et al. (1974) was calculated by using the following equation: SI = (10M + 5S3 + 3S2 +2S1)/N. Nevertheless, a migration of photosynthetic assimilates is carried out from vegetative tissues to growing fruit bunch, causing exhaustion of leaf system (Maillard et al., 1974). Thus, only trees with 4 to 6 leaves broken were considered at stage S2, whatever the fruit bunch aspect.

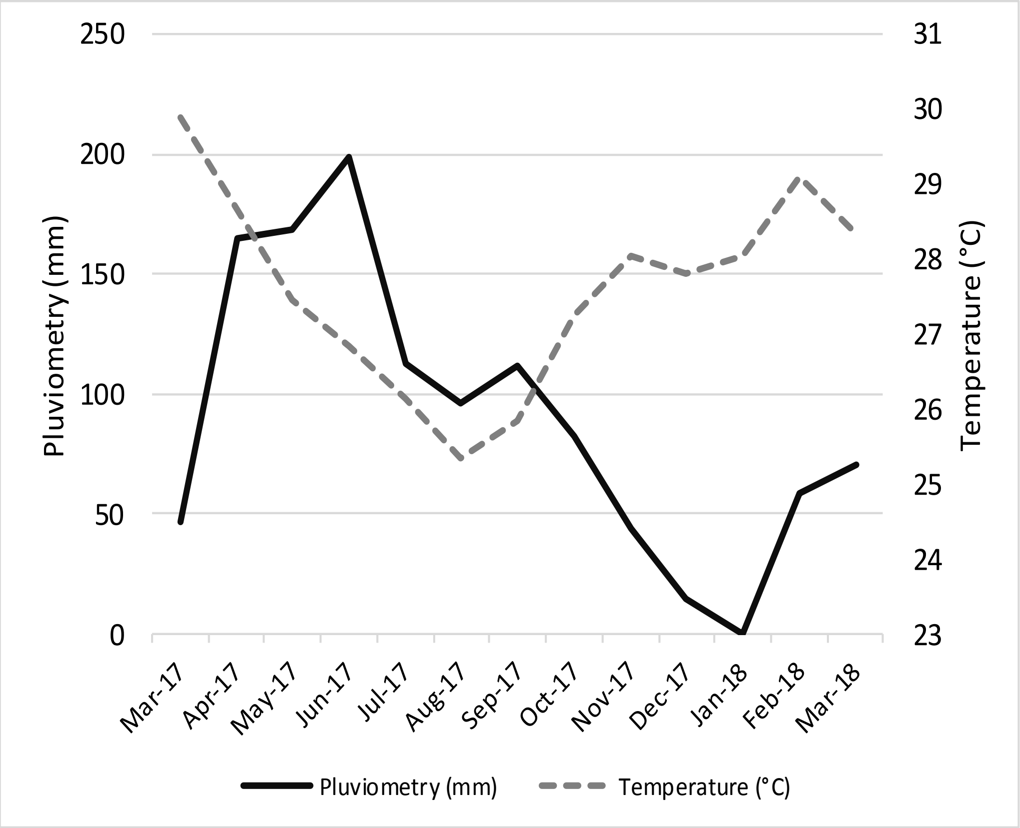

Figure 1: Variation of the mean temperature and pluviometry during the period of study.

RESULTS

Correlations between drought damage traits

The ten oil palm genotypes were evaluated for their responses to drought. Table 1 present the means of several drought damages traits for the different genotypes. To gain insight into the relationships between several drought damages traits, a clustering and correlation analysis was performed (Figure 2). Traits from the same group clustered closely, indicating strong correlations with each other. Furthermore, clustering analysis of the drought damages data highlighted two main groups (A and B). Group (A) comprised leaves damages (NGBL and NFL) and central leaf cabbage toppled (NLCT), which were strongly and positively correlated. This result shows that leaves damages caused by drought, usually induce toppling over central leaf cabbage (Picture 1). The second group (B) was composed of traits in relation to number of unopened leaves (NUL) and number of base leaves dry out (NBLD) with moderate correlation values. We concluded that NUL and NBLD traits are not as relevant as NGBL, NFL and NLCT traits for drought study in adult palms.

Drought tolerance ranking of the ten oil palm progenies using integrated PCA score values

Principal component analysis (PCA) was performed based on the drought damages data collected in this study to discriminate the ten genotypes according to their tolerance to drought. The first three major axes explained 97.06% of the total variance in response to drought treatment (84.17% for F1, 8.18% for F2 and 4.71% for F3). The ten progenies were grouped into three main clusters (I, II and III). Cluster I gathered together the genotypes L9, L8, L3, L1, L2 and L10. Cluster II encompassed the genotypes L5, L7 and L4 whereas, the cluster III was composed of L7 genotype (Figure 3). We developed the following formulas based on the results of PCA:

(1) F1 = 0.440 x NUL + 0.467 x NGBL + 0.436 x NFL + 0.413 x NBLD + 0.478 x NLCT

(2) F2 = 0.220 x NUL + (- 0.311) x NGBL + (-0.567) x NFL + 0.730 x NBLD + (-0,013) x NLCT

(3) F3 = (-0.393) x NUL + 0.071 x NGBL + 0.124 x NFL + 0.244 x NBLD + (-0.032) x NLCT

In addition, a ranking value for each genotype was calculated using a separate formula

(4) PCA score value = (84.17% x F1) + (8.18% x F2) + (4.71% x F3)

Where F1, F2 and F3 are the first three dimensions or axes explain 97.06% of total variance in response to drought treatment (84.17%, 8.18% and 4.71% for F1, F2 and F3 respectively)

Then, the ten oil palm genotypes were ranked for drought tolerance based on the PCA ranking values (Table 2). The genotype L7 (cluster III) had the highest PCA ranking value, suggesting that they were highly drought sensitive. In contrast, L9, L8, L3, L1, L2 and L10 (cluster I) displayed the lowest ranking and then were found to be the most tolerant genotypes within the collection. The genotypes L5, L6 and L4 (cluster II) showed intermediate values suggesting that they were moderately tolerant to drought.

Drought tolerance ranking of the ten oil palm progenies using sensibility index (SI)

To verify the ranking of ten oil palm genotypes under stress, sensibility index was calculated according to Maillard et al. (1974) formula. The results obtained are summarized in the table 3. This results show that genotype L7 confirmed its high sensitivity to drought with higher SI value (SI = 4.33). Likewise, L9 (SI = 0.23), L8 (SI = 0.33), L2 (SI = 0.43) and L10 (SI = 0.57) appeared as the most drought tolerant genotypes, as well as genotypes L5 (SI = 2.30), L4 (SI = 0.98) and L6 (SI = 0.95) which confirmed their intermediate tolerance to drought as in PCA ranking. In contrast, L1 (SI = 0.87) and L3 (SI = 0.80) showed intermediate tolerance to drought while classified as a tolerant genotype to drought by PCA analysis.

Table 1: Means of number of green broken leaves (NGBL), number of folded leaves (NFL), number of unopened leaves (NUL), number of base leaves dry out (NBLD) and number of trees with central leaf cabbage toppled (NLCT) for ten oil palm genotypes under drought condition.

GENOTYPES	DROUGHT DAMAGES TRAITS				
	NUL	NGBL	NFL	NBLD	NLCT
L1	4.58±0.71	0.36±0.68	0.12±0.37	0.03±0.26	0.00±0.00
L2	3.97±0.66	0.43±0.90	0.05±0.28	0.40±0.49	0.00±0.00
L3	4.25±0.79	0.45±0.92	0.08±0.28	0.37±0.86	0.00±0.00
L4	4.37±0.58	0.25±0.83	0.12±0.45	3.88±1.00	0.00±0.00
L5	4.9±0.79	2.18±2.61	0.05±0.22	3.57±1.28	0.07±0.25
L6	4.13±0.85	1.33±1.74	0.20±0.60	3.55±0.85	0.03±0.18
L7	5.47±0.78	5.17±3.90	1.43±1.51	5.60±1.49	0.13±0.34
L8	3.98±0.65	0.6±0.78	0.12±0.32	0.03±0.18	0.00±0.00
L9	3.87±0.59	0.72±0.63	0.25±0.43	0.12±0.32	0.00±0.00
L10	3.83±0.55	1.27±1.56	0.02±0.13	0.38±0.61	0.00±0.00

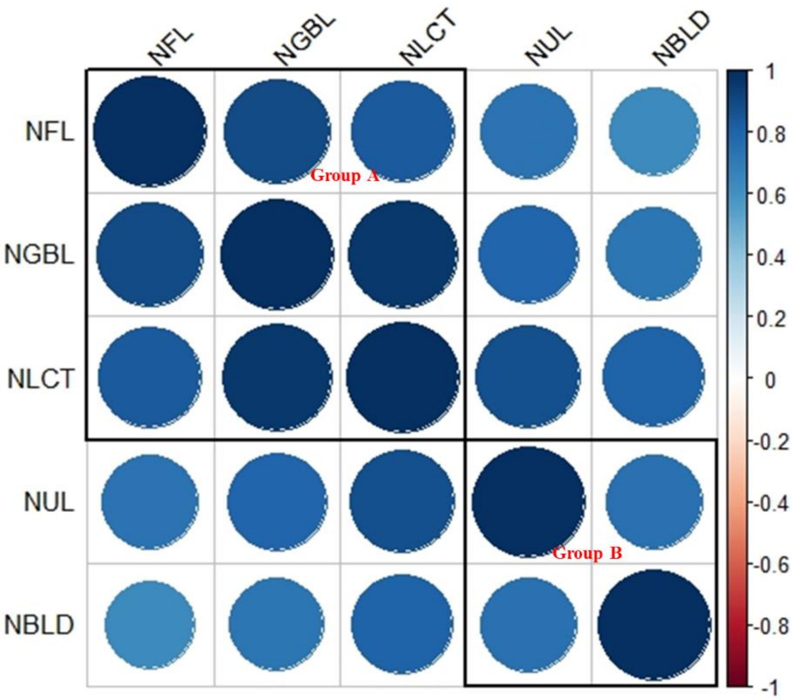

Figure 2: Correlation between all the drought damages traits in oil palm. Blue color depicts positive correlation while red color means negative correlation. Group A and group B correspond to the clusters of traits. NGBL=number of green broken leaves, NFL=number of folded leaves, NUL=number of unopened leaves NBLD=number of base leaves dry out NLCT=number of trees with central leaf cabbage toppled.

Picture 1: Toppling over of the central leaf cabbage of oil palm.

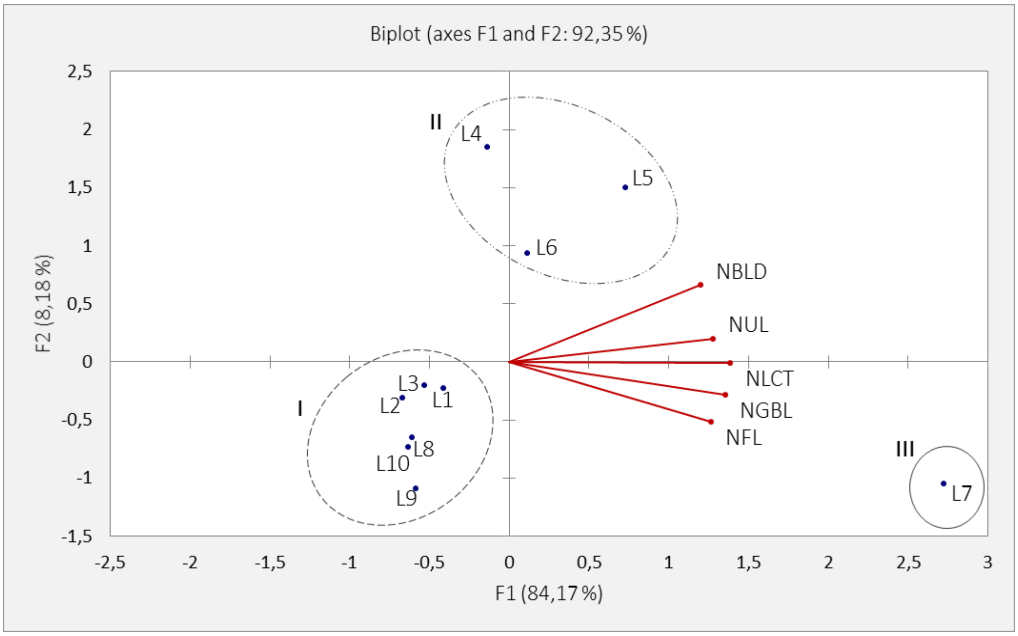

Figure 3: Principal components analysis (PCA) for drought damages traits of ten oil palm progenies. Percentages in brackets correspond to the explained variances of the corresponding components or axes. The circles represent the different clusters.

Table 2: PCA ranking values of the drought damages traits of ten oil palm genotypes.

GENOTYPES	F1	F2	F3	Ranking	Numeric rank
L7	7.82	2.87	-2.39	670.48	1
L5	4.70	2.98	0.08	420.69	2
L6	4.01	2.97	0.01	361.68	3
L4	3.69	3.65	0.06	341.08	4
L10	2.44	0.71	0.00	211.49	5
L3	2.27	1.02	0.00	199.13	6
L1	2.25	0.85	0.00	196.37	7
L9	2.20	0.57	0.00	190.04	8
L2	2.13	1.00	0.00	187.73	9
L8	2.10	0.64	0.00	181.73	10

Table 3: Drought sensitivity index (SI) of the ten oil palm genotypes.

GENOTYPES	S1	S2	S3	M	N	SI
L1	26	0	0	0	60	0.87
L2	10	2	0	0	60	0.43
L3	21	2	0	0	60	0.80
L4	28	1	0	0	60	0.98
L5	42	13	3	0	60	**2.30**
L6	18	7	0	0	60	0.95
L7	56	36	8	0	60	**4.33**
L8	10	0	0	0	60	0.33
L9	7	0	0	0	60	0.23
L10	5	8	0	0	60	0.57

S1 = accumulation stage of five or six spear leaves in the centre of the crown, S2 = stage of four to six green leaves collapsed or broken, S3 = stage where all leaves at the base of the crown dried and foliage in the centre of the crown collapsed, M = number of dead tree and N = number of healthy and productive trees.

DISCUSSION

Oil palm is susceptible to water deficit which can differentially affect growth traits according to the genotype and drought stress severity (Legros et al., 2009; Cha-um et al., 2013). This has been demonstrated in several study where seedlings of oil palm genotypes were evaluated based on growth parameters under drought stress (Silva et al., 2017; Duangpan et al., 2018). Indeed, Duangpan et al. (2018) and Labo et al. (2016) set in their studies that oil palm seedlings are more susceptible to abiotic stress, in this case drought, than adult palms. However, our principal component analysis (PCA) results have shown that palms are also very vulnerable to drought in the adult stage particularly considering number of green broken leaves (NGBL), number of folded leaves (NFL) and central leaf cabbage toppled (NLCT) parameters; according Suresh (2013) broken green leaves are observed when the water deficit increases to 500 mm $year^{-1}$.

PCA is considered a powerful method for analyzing and interpreting the data. It was successfully used as a multivariate analysis to cluster genotypes according to their stress tolerance levels as measured by various phenotypes under either controlled or field conditions (Liu et al., 2010). In the present study, PCA successfully clustered ten oil palm genotypes into three groups based on drought damages traits (NGBL, NFL, NUL, NBLD and NLCT) under drought condition; drought sensitive genotype L7, drought tolerant genotypes L9, L8, L3, L1, L2 and L10 and moderately tolerant to drought genotypes L5, L6 and L4. These results indicated the possibilities of using PCA based on drought damages parameters to evaluate drought tolerance in adult oil palms, as Duangpan et al. (2018) has used to evaluate drought tolerance in oil palm seedlings. However sensibility index (SI) formula of Maillard et al., (1974) did not exactly confirm PCA results. This could be due to the absence of "dry of fruit bunch" parameter in S2 stage; but SI equation has weakness that sometimes lead to misclassification according to intensity of drought (Maillard et al., 1974; Nodichao, 2008) .

Conclusion

In this study, ten oil palm genotypes from germplasm collection of CRA-PP research institute was screened for drought tolerance based on drought damages traits. Number of green broken leaves (NGBL), number of folded leaves (NFL) and number of trees with central leaf cabbage toppled (NLCT) are more relevant traits for drought study in adult palm trees according PCA results. PCA ranked the genotypes L9, L8, L3, L1, L2 and L10 as the most tolerant genotypes to drought. In contrast, the genotype L7 was highly sensitive to drought and L5, L6 and L4 were moderately tolerant to drought genotypes. Future studies may rely on these results to further drought stress investigations with the aim of releasing highly drought tolerant genotypes for the benefit of local farmers in Benin and West Africa.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

LWY and LN designed the field work, LWY performed the field work, gave formal analysis and software, analyzed and drafted the manuscript, LN supervised the work, read and improved the manuscrit ; H A-S and CA gave conceptual advice read and improve the manuscrit. All authors have read and approved the final manuscript.

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