

## Selection of 2 Origins of *Terminalia Ivorensis* A. Chev. By Means of Typological and Discriminant Clusterings



Science

**KEYWORDS :** Ghana, Cameroon, Côte d'Ivoire, Principal Component Analysis, Hierarchical Cluster Analysis, discriminant model, basic wood density

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### ABSTRACT

*The wood density is a key criterion for the Origins selecting and thus their valuing. In past, to select Origins, criteria of the plant growth, such as the circumference at 1.3 m from the ground, were used. Thus, to select the best*

*Origins of Terminalia ivorensis the circumference at 1.3 m from the ground, the Pilodyn penetration depth and the basic wood density were measured. Sixteen Origins from Côte d'Ivoire, Ghana and Cameroon were used in comparative Origins trial. Hierarchical Cluster, Principal Component and Factorial Discriminant Analyses were used. Three morphologically distinct clusters were evidenced. The cluster C2 composed of Origins 2 and 9 expressed the smallest values of the Pilodyn penetration depth. It was selected. Two discriminant functions, named  $Z1 = -38.111 + 0.761 \cdot \text{Pilo} + 0.162 \cdot \text{Circ}1.3$  and  $Z2 = -3.664 + 0.546 \cdot \text{Pilo} - 0.105 \cdot \text{Circ}1.3$  significantly and completely discriminated the 3 clusters evidenced. They will allow the predicting of the membership cluster of a new individual from its values of the circumference at 1.3 m from the ground and the Pilodyn penetration depth.*

### 1. INTRODUCTION

Called Terminalia ivorensis in Latin, Framiré in French, Idigbo in English speaking countries, it is part of Combretaceae (Anonymous, 1989). Forest species growing in transition area between semi-deciduous dense forest and the evergreen one, Terminalia ivorensis grows from Guinea to Cameroon as well as Gabon. It is used in reforestation. Its hard wood is appreciated in carpentry and cabinetwork. Selection of elite trees in this botanical group uses the criterion of vegetative vigour and that of shape. In recent works, Ahoba et al. (2015) showed the relevance of parameters the plant vigour, namely the circumference at 1.3 m from the ground in the discriminating of 8 origins of Gmelina arborea Roxb. Following the same idea, using the univariate approach, 16 Origins of Terminalia ivorensis were tested here. The study revealed Origin 2 as the best (Ahoba et al, 2016; submitted for publication). Moreover, no study reported the multivariate approach regarding the structuring of the variation of these 16 Origins. Thus, the multivariate structuring of 16 Origins of Terminalia ivorensis is badly known. The knowledge of this structuring will allow the understanding of the relevance of each of the 2 approaches. Thus, we assume that the multivariate approach might provide more individuals in interest clusters than the univariate one. The present study aimed to select the best Origins of Terminalia ivorensis thanks to the multivariate approach.

### 2. MATERIALS AND METHODS

Plant material was composed of 16 Origins from Terminalia ivorensis. Their origin countries, the geographic coordinates and the rainfall of these countries were reported (Table 1). This is species preferring dry forest and full light, losing its leaves each year and whose economical value is very important. The distribution area corresponds to the semi-deciduous dense forest zone that spreads from the

forest zone of Guinea to West of Cameroon, with frequent penetration in the evergreen area of forest in Côte d'Ivoire. Tree stumps produce vigorous shoots which quickly grow.

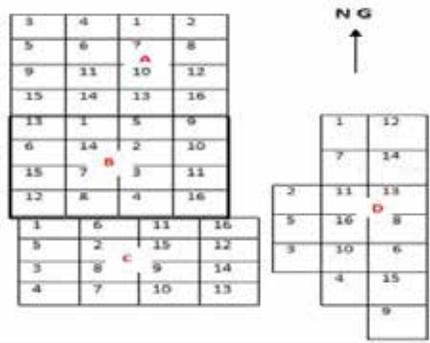
**Table 1: Origin and geographic coordinates of 16 origins tested.**

| N° Local | Country       | Origins        | Latitudes | Longitudes | Altitudes (m) | Rainfall (mm) |
|----------|---------------|----------------|-----------|------------|---------------|---------------|
| 1        | Côte d'Ivoire | Loviguié       | 5° 45' N  | 4° 19' O   | 100           | 1500          |
| 5        | Côte d'Ivoire | Yapo           | 4° 06' N  | 5° 44' O   | 50-100        | 1600          |
| 9        | Côte d'Ivoire | Abengourou     | 6° 43' N  | 3° 30' O   | 260           | 1300          |
| 13       | Côte d'Ivoire | Bamo           | 5° 56' N  | 4° 13' O   | 80            | 1500          |
| 15       | Côte d'Ivoire | Mopri          | 5° 50' N  | 4° 50' O   | 80            | 1400          |
| 6 et 10  | Ghana         | PraAnum        | 6° 15' N  | 1° 15' O   | 150           | 1650          |
| 11et16   | Ghana         | Bobiri         | 6° 45' N  | 1° 15' O   | 150           | 1650          |
| 8        | Ghana         | Krokosua Hills | 6° 30' N  | 2° 45' O   | 250-350       | 1650          |
| 3        | Ghana         | N'Dumeri       | 5° N      | 2° 15' O   | 150           | 2000          |
| 7 et 2   | Ghana         | Mankrang       | 7° 15' N  | 2° O       | 150-350       | 1400          |
| 14       | Ghana         | TanoAnhwia     | 5°45' N   | 2° 30' O   | 150           | 1650          |
| 12       | Ghana         | Volta River    | 6° N      | 0° O       | 350-500       | 1150          |
| 4        | Cameroon      | Kumba          | 4°32' N   | 9°19' EAST | 350           | 2600          |

### Experimental design

Each of 16 origins was used as a factor in a Randomised Complete Block Design with one replication. Treatment was defined as each of levels of factor Origin. Four blocks

noted A, B, C, D, with each 16 experimental plots, in which the 16 treatments were allocated (Figure 1). In all, 64 unit plots with 100 plants per origin and per unit plot were used. Regarding the origin 14 from Ghana, by reason of unavailability of the seedlings, its counts in unit plots were reduced in half, that is to say 50 (Cabaret, 1988). Origins were planted on 22 ha. Seedlings were spaced 3.33 m on rows and 8 m between rows. The trial was installed under poisoned forest with seedlings grown in nursery. To develop hole for planting seedlings, trees whose diameter was over 20 cm were felled.



**Fig. 1:** Experimental design of the comparative Origins trial of *Terminalia ivorensis* set up at Mopri, Côte d'Ivoire.

Key of origins : 1: Côte d'Ivoire (Lovigué); 2: Ghana (Mankrang); 3: Ghana (N'Dumeri); 4: Cameroun (Kumba Town); 5: Côte d'Ivoire (Yaposud); 6: Ghana (PraAnum); 7: Ghana (Mankrang); 8: Ghana (Krokosua); 9: Côte d'Ivoire (Abengourou); 10: Ghana (PraAnum); 11: Ghana (Bobiri); 12: Ghana (Volta River reserve); 13: Côte d'Ivoire (Bamo); 14: Ghana (TanoAnwhia); 15: Côte d'Ivoire (Mopri); 16: Ghana (Bobiri).

#### Trees choice, measurements and sampling on trees

For all the 4 blocks, 64 squared patches measuring 4 acres were laid out at the centre of each unit plot to avoid edge effects. These 4 acres allowed the sampling from 2 to 6 trees per unit plot considering different mortalities from plot to plot. Two hundred and ninety six (296) trees from 16 origins distributed in the 4 blocks were thus selected. On each tree selected, the circumference at 1.30 m from the ground was recorded using a tape measure. Measurements with the Pilodyn 6 joule-penetration depth have subsequently been carried out on bark at 1.30 m from the ground (Figure 2). This, in the East-West direction, to harmonise the side of penetration for all trees. Finally, a core sampling was taken at 1.30 m from the ground in the East - West direction using a Pressler borer of 5 mm well sharpened.



**Fig. 2:** The pilodyn 6 joules (wood tester) used for experimentation.

#### Determination of the basic wood density

The obtained core sampling (296) were subdivided into three parts: A (sapwood), B (perfect wood), C (heart area) thus giving 890 sub-cores whose each was subjected to the determination of wood basic density via the method of full saturation (Polge, 1966). For this study, only average basic density per tree was taken into account to compare the origins. Likewise, the link between the wood basic density and the Pilodyn penetration depth was established by means of the Pearson's linear correlation. These basic densities (ID) were obtained from the following relationship of Keylwerth (1954) and Polge (1966):

$M_s$  = Weight of the sub - core to the saturated state  
 $M_0$  = Weight of the sub - core to the anhydrous state

#### Data analysis

Softwares SPSS and Xlstat, versions 16.0 and 2007, respectively, were used to strip collected data. Hierarchical Cluster (HCA), Principal Component (PCA) and Factorial Discriminant Analyses (FDA) were used to structure the variability observed.

### 3. RESULTS

#### Data contractibility, axes choice and data interpreting for the PCA

The index of Kaiser-Meyer-Olkin was 0.566. Such a value is considered to be poor, according to Kaiser's scale, because it ranges from 0.5 to 0.6 ([http://eric.univlyon2.fr/~ricco/tanagra/fichiers/fr\\_Tanagra\\_KMO\\_Bartlett.pdf](http://eric.univlyon2.fr/~ricco/tanagra/fichiers/fr_Tanagra_KMO_Bartlett.pdf), accessed on the 19 th of May 2016) The sphericity test of Bartlett, revealing that at least one of the correlations between measured variables significantly differed from zero, was very significant (approximate  $\chi^2 = 12.349$ ;  $df = 3$ ;  $p$ -value = 0.006). Likewise, the determinant of correlation matrix differed from zero ( $D = 0.391$ ). Consequently, collected data were contractible.

Three axes, for model returning at least 80% information ( $F1/F2/F3 = 100\%$ ), were chosen. The plane 1-2 expressed 67.42% total variation. The first axis accounted for 33.89% of total variation. It is represented by the basic wood density. Thus, it represents the matter quantity in the wood. The second axis, showed 33.53% of the unexplained variation by the component 1. It is determined by the circumference at 1.3 m from the ground. It reveals the growth in diameter of trees. The third axis, displayed

32.58% of the unexplained variation by the axis 3. It expresses the Pilodyn penetration depth. It shows the resistance to the penetration of trees trunk (Table 1).

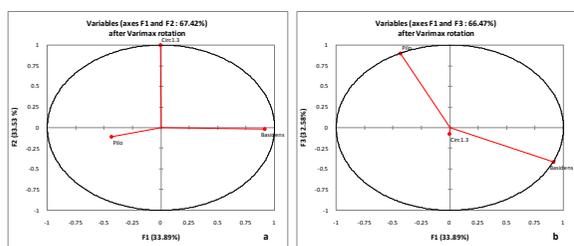
The casting of variables on the planes 1-2 and 1-3 of the correlation circles showed different levels of communality. Thus, on the plane 1-2, the first one, corresponding to the circumference at 1.3 m from the ground, was the best represented. The second one, represented by the basic wood density, was fairly represented. The third one, linked with the Pilodyn sinking depth, was the least represented (Figure 1a). In contrast, on plane 1-3 of the correlation circle, 2 levels of communality were identified. First, corresponding to the Pilodyn penetration depth and basic wood density, were the best represented. Second, represented by the circumference to 1.3 m from the ground, was badly represented (Figures 1a and 1b).

Likewise, the casting of individuals on the planes 1-2 and 1-3 allowed their structuring. On the plane 1-2, individuals were structured in 2 large clusters. First, composed of clusters 1 and 2. It was constituted of 8 individuals, namely Org1, Org2, Org3, Org8, Org9, Org12, Org13 and Org14.

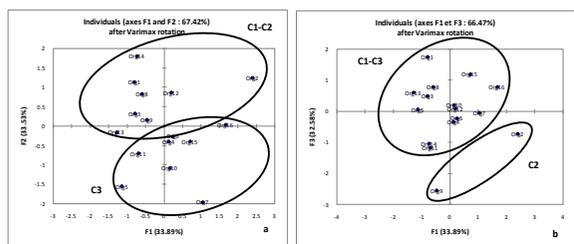
Second, also consisted of 8 individuals, namely Org4, Org5, Org6, Org7, Org10, Org11, Org15 and Org16. On the plane 1-3, individuals were also clustered in 2 broad clusters. First, composed of clusters 1 and 3. It was constituted of 14 individuals, that is to say Org1, Org3, Org4, Org5, Org6, Org7, Org8, Org10, Org11, Org12, Org13, Org14, Org15, Org16. Second, comprised of 2 individuals, namely Org2 and Org9 (Figure 2a and 2b).

**Table 1: Cumulated percentage and communalities on each of 3 axes.**

|                 | F1    | F2    | F3     |
|-----------------|-------|-------|--------|
| Variabilité (%) | 33.89 | 33.53 | 32.58  |
| Cumulated %     | 33.89 | 67.42 | 100.00 |
| Circ1.3         | 0.000 | 0.994 | 0.006  |
| Pilo            | 0.187 | 0.012 | 0.801  |
| Basidens        | 0.829 | 0.000 | 0.170  |



**Fig. 1 : Scatter plots of the measured variables on the planes 1-2 and 1-3 of the correlation circles of the PCA. a, the plane 1-2; b, the plane 1-3.**



**Fig. 2 : Scatter plots of the individuals on the planes 1-2 and 1-3 of the factorial maps of the PCA. a, the plane 1-2; b, the plane 1-3.**

**Variation among the 16 individuals observed thanks to HCA**

The lack of predefined clusters and the existence of less than 100 individuals, allowed the choice of the HCA, instead the K-Means clustering (<http://www.lemoal.org/spss/>, accessed on the 20 th of May 2016). These individuals were divided into 3 clusters, namely C1, C2 and C3, consisted of 6, 2 and 8 individuals, respectively. These accounted for 37.50, 12.50 and 50%, respectively. These percentages, all higher than 10% level, in each cluster, met the main criterion of choice of the HCA method. Moreover, at truncation point 12.5 from the dendrogramme scale, the truncation was carried out. At this point, 3 clusters were identified. Such differences were displayed by the Multivariate Analysis of Variance (p-value / Pillai's Trace, Wilks' Lambda, Hotelling's Trace, Roy's Largest Root= <0.001; Table 2). The Statistics of Wilks' Lambda being equal to 0.096, tending towards 0, suggested that cluster centroids would be distinct (<http://tutoriels-data-mining.blogspot.fr/2012/07/analyse-discriminante-lineaire.html>, accessed on the 20 th May of 2016).

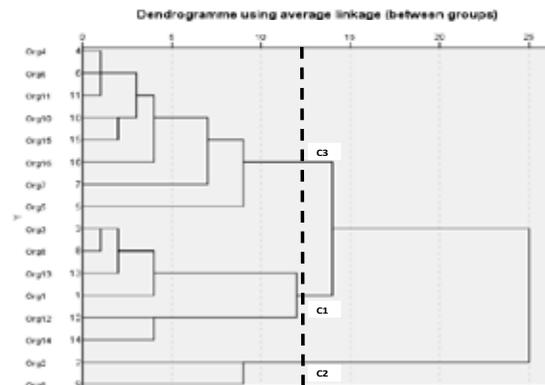
Further analysis revealed that the 3 measured variables partially discriminated the 3 clusters (Table 3; Figure 3). Thus, the cluster C1 was composed of 6 individuals, namely Org1, Org3, Org8, Org12, Org13 and Org14. It was characterised by high circumference at 1.3 m from the ground, by high Pilodyn penetration depth, but by low basic wood density (Table 3). The cluster C2 consisted of 2 origins, especially Org2 and Org9. It was marked by high circumference at 1.3 m from the ground, by high basic wood density, but by low Pilodyn penetration depth. The cluster C3 comprised 8 individuals, particularly Org4, Org5, Org6, Org7, Org10, Org11, Org15 and Org16. It stood out from the 2 previous by low circumference at 1.3 m from the ground, by low basic wood density, but by high Pilodyn penetration depth (Table 3).

**Table 2 : Assessment of the cluster effect on the simultaneous expression of 3 measured by means of the Multivariate Analysis of Variance (Manova).**

| Factor  | Multivariate test  | Value | F      | Hypothesis df | Error df | p-value |
|---------|--------------------|-------|--------|---------------|----------|---------|
| Cluster | Pillai's Trace     | 1.341 | 8.131  | 6             | 24       | <0.001  |
|         | Wilks' Lambda      | 0.096 | 8.191  | 6             | 22       | <0.001  |
|         | Hotelling's Trace  | 4.897 | 8.161  | 6             | 20       | <0.001  |
|         | Roy's Largest Root | 3.645 | 14.581 | 3             | 12       | <0.001  |

**Table 3: Classification of the clusters means of outputted by the HCA using the 5 parameters according to Student-Newman-Keuls' test.**

|         | Circ1.3  | Pilo    | Basidens |
|---------|----------|---------|----------|
| C1      | 113.217a | 28.355a | 329.167a |
| C2      | 113.65b  | 24.115b | 374.15a  |
| C3      | 100.538b | 27.394b | 349.062b |
| Mean    | 109.135  | 26.621  | 350.793  |
| F       | 10.584   | 10.274  | 8.442    |
| p-value | 0.002    | 0.002   | 0.004    |



**Fig. 3: Partitioning of the hierarchical tree of 16 origins of Terminalia ivorensis by means of the average linkage between clusters as an aggregation criterion**

**Robustness of 3 clusters identified by using the FDA**

It was analysed by means of the differences among groups, the validation of the method of Wilks' Lambda, the discriminant power of axes and the examination of the com-

munalities.. Before such an analysis, the relevantness of means to include in the discriminant model was examined. For that, the Variance Inflation Factor (VIF) was calculated. To be selected, a mean must express a VIF lower than 10. All calculated means displayed VIF smaller than 10 (VIF / Circ1.3 = 1.072 ; VIF / Pilo = 2.554 ; VIF / Basidens = 2.476). Therefore, these 3 means from 3 measured variables were selected for the rest of the study (Table 4).

Regarding the existence of differences among the 3 clusters, 3 criteria were analysed : 1) the examining of the variances, 2) the analysis of the Snedecor-Fisher F statistics and 3) the analysis of the Wilks' Lambda. With respect to the means, they appeared to be the most discriminant (Mean / Circ1.3 = 113.220; Mean / Pilo = 28.355). For the Snedecor-Fisher F statistics, those from 2 means aforesaid were discriminant (F / Circ1.3 = 10.584, p-value = 0.002; F / Pilo = 10.274, p-value = 0.002). As for Wilks' Lambda, those from 2 means were smaller or equal to 0.9 with the same aforementioned p-values ( $\lambda$  / Circ1.3 = 0.380;  $\lambda$  / Pilo = 0.387). Therefore, the analysis of these 3 criteria showed the existence of differences among the groups evidenced.

The validation of the method of Wilks' Lambda was achieved estimating: 1) statistics M of Box, 2) the global correlation as well as 3) Wilks' Lambda linked with stepwise technique. As for the Box's M statistics, this was high, but insignificant (M = 3.554; p-value = 0.409), suggesting the choice of the Linear Discriminant Analysis instead the quadratical one. As far as the global correlation is concerned, 2 discriminant functions were evidenced. First, the eigenvalue was equal to 2.373. It discriminated in the proportion of 65.60% the clusters evidenced. Its global correlation tended toward 1 (r = 0.839). Second, the eigenvalue was equal to 1.245. It discriminated the evidenced clusters in the proportion of 34.40%. Its global correlation also tended toward 1 (r = 0.745). The Wilks' Lambda linked to stepwise technique displayed that the function 1 recorded low but significant Wilks' Lambda (Lambda / function 1 = 0.132; p-value = <0.001). Likewise, the function 2 also displayed low but significant Wilks'  $\lambda$  ( $\lambda$  / function 2 = 0.445; p-value = 0.001). Therefore, the 2 discriminant functions were selected to model the technological wood characteristics. These results allowed the validation of the method of Wilks' Lambda.

The cluster C1 were placed in majority in the negative and positive parts of canonical function F1, while the clusters C2 and C3 were placed in the negative part of the canonical function 2 (Figure 4).

The discriminant power of axes was examined thanks to the analysis of the linear discriminant functions 1 and 2. The function 1 corresponding to the study is spelt :  $Z1 = -38.111 + 0.761 \cdot Pilo + 0.162 \cdot Circ1.3$ . The discriminant function 2 is written  $Z2 = -3.664 + 0.546 \cdot Pilo - 0.105 \cdot Circ1.3$ . From the linear equation  $Z = Z0 + W1X1 + W2X2$ , where Z is the discrimination score; Z0 represents the intercept of discrimination score; W1, the first weight of the discrimination ; X1 is the first variable linked to the first discrimination weight; W2 the second weight of the discrimination ; X1 is the second variable related to the second discrimination weight.

As far as the function 1 is concerned, its Z0, W1 and W2 were equal to -38.111, +0.761 and +0.162, respectively. Regarding the discriminant function 2, its Z0, W1 and W2 were equal to -3.664, +0.546 and -0.105, respectively. These Z0, W1 and W2 represented the estimated coefficients of the discriminant functions 1 and 2.

The analysis of the communalities was achieved by using the confusion matrix. The latter displayed that in clusters C1, C2 and C3, 100% individuals were well reclassified thanks to discriminant functions 1 and 2 (Table 4).

There is reduced number of variables containing the sufficient information allowing the complete discriminating of clusters. These are the circumference at 1.3 m from the ground and the Pilodyn penetration depth.

The examination of the pairwise distances among the 3 clusters was achieved via the Mahalanobis' distances (distance C1-C2 = 19.791; distance C1-C3 = 12.876; distance C2-C3 = 10.187). The Wilks' statistics test linked with the assumption of the equality of average vectors was significant (Lambda = 0.096; p-value <0.0001). Consequently, at least 2 clusters very significantly differed from each other (Table 5). A closer analysis of the significances of those, via the Hotelling's T-squared test, showed that the 3 evidenced clusters are very highly and statistically different from each other (p-value / C1-C2= <0.001; p-value / C1-C3= <0.001; p-value / C2-C3= <0.001). Consequently, the 3 evidenced clusters constituted 3 morphological differentiation clusters (Tables 6 and 7; Figure 4).

**Table 4 : Communalities of individuals composing the 3 clusters by means of the confusion matrix**

|          |       |                                  | Predicted Group Membership |       |       |       |
|----------|-------|----------------------------------|----------------------------|-------|-------|-------|
|          |       | Average Linkage (Between Groups) | C1                         | C2    | C3    | Total |
| Original | Count | C1                               | 6                          | 0     | 0     | 6     |
|          |       | C2                               | 0                          | 2     | 0     | 2     |
|          |       | C3                               | 0                          | 0     | 8     | 8     |
|          | %     | C1                               | 100.0                      | 0.0   | 0.0   | 100.0 |
|          |       | C2                               | 0.0                        | 100.0 | 0.0   | 100.0 |
|          |       | C3                               | 0.0                        | 0.0   | 100.0 | 100.0 |

**Table 5: Multicollinearity statistics.**

| Statistics | Circ1.3 | Pilo  | Basidens |
|------------|---------|-------|----------|
| Tolerance  | 0.933   | 0.391 | 0.404    |
| VIF*       | 1.072   | 2.554 | 2.476    |

**Key :** Variance Inflation Factor calculated as the inverse of the tolerance.

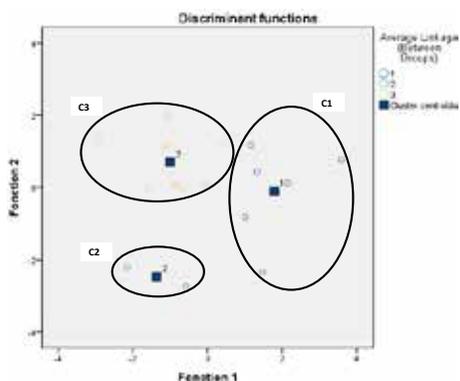
**Table 6: Relationship among the 3 clusters by using the Mahalanobis' distance**

|    | C1     | C2     | C3     |
|----|--------|--------|--------|
| C1 | 0      | 19.791 | 12.876 |
| C2 | 19.791 | 0      | 10.187 |
| C3 | 12.876 | 10.187 | 0      |

**Table 7: Significance of the distances among the 3 clusters C1-C2, C1-C3 and C2-C3 through Hotelling's T-squared test.**

| Distance between | Hotelling's T-Squared | F       | df1 | df2 | p-value |
|------------------|-----------------------|---------|-----|-----|---------|
| C1-C2            | 1576.779              | 675.763 | 2   | 6   | <0.001  |
| C1-C3            | 7269.618              | 3355    | 2   | 12  | <0.001  |

|       |          |      |   |   |        |
|-------|----------|------|---|---|--------|
| C2-C3 | 3287.307 | 1461 | 2 | 8 | <0.001 |
|-------|----------|------|---|---|--------|



**Figure 4:** Scatter plot of 16 Origins of *Terminalia ivorensis* on the plane 1-2 of the factorial map of canonical functions 1 and 2 of the FDA.

### Discussion

Two Origins out of 16 of *Terminalia ivorensis* from cluster C2 were selected thanks to the analysis of the variability, mainly of their technological characteristics. Ahoba et al., (2016, submitted for publication) analysed the same 16 Origins, but by using the univariate approach. Their study revealed that the Origin 2 from Ghana showed the best Pilodyn penetration depth. Resorting to the multivariate method, cluster C2 composed of Origins 2 and 9 from Ghana and Côte d'Ivoire, respectively, displayed the weakest Pilodyn penetration depth, but a high basic wood density (Table 3).

The means of 3 measured variables used in the study were revealed relevant to achieve the PCA (Figures 1a, 1b, 2a and 2b; Table 1). They expressed acceptable factorial structure having allowed the meeting of criteria related to the validating of the PCA.

The castings of variables and individuals on planes 1-2 and 1-3 allowed the exploring of the variability structuring (Figures 1a, 1b, 2a and 2b; Table 1). From those, C1-C2 and C3 as well as C1-C3 and C2 clusters were identified (Figure 2a and 2b).

The 16 Origins were structured into 3 morphologically distinct clusters (Table 3; Figure 3). Ahoba et al., (2016, submitted for publication) evidenced 2 clusters whatever the used variable, by resorting the univariate method. Therefore, multivariate method is more reliable than the univariate one (Issali et al., 2014 a).

Cluster C2 consisting of Origins 2 and 9 expressed the smallest values of the Pilodyn penetration depth but the largest value of the basic wood density. The Pilodyn penetration depth is negatively correlated with the basic wood density (Ahoba et al., 2016, submitted for publication). In Ahoba et al., (2016, submitted for publication), by using the univariate method, sole the Origin 2 showed the lowest values of the Pilodyn penetration density. Thus, it was selected for multi-local and multi-annual trials before its releasing beside Sodefor (Société de Développement Forestier) from Côte d'Ivoire for its exploiting. Consequently, for our work, the Origins 2 and 9 must undergo to the multi-local and multi-annual trials before authorising their exploiting.

Out of 3 used variables, sole 2, namely, the circumference

at 1.3 m from the ground and the Pilodyn penetration depth contain the sufficient information allowing the complete discrimination of clusters. In Issali et al., (2014 b) and Issali et al., (2014 c) analysing the structuring of 6 cocoa hybrids relatively to their collogenic and somatic embryogenesis as well as their response to the phenology, identified the number of collogenic explants and the leaves flush as the most relevant variables. For our future works, the circumference at 1.3 m from the ground and the Pilodyn penetration depth will be measured for predicting purposes.

discriminant functions 1 and 2, namely  $Z1 = -38.111 + 0.761 \cdot \text{Pilo} + 0.162 \cdot \text{Circ1.3}$  and  $Z2 = -3.664 + 0.546 \cdot \text{Pilo} - 0.105 \cdot \text{Circ1.3}$ , significantly and completely discriminated the 3 clusters identified. They modeled the variations of discrimination scores as a function of the circumference at 1.3 m from the ground and the Pilodyn penetration depth. As regards function 1, the individuals belonging to cluster C1 will express circumferences at 1.3 m from the ground stretching from 105.4 to 122.3 cm. Their Pilodyn penetration depth will oscillate 26.02 to 30.33 mm. Therefore, Z1 will fluctuate from -1.235 to 4.783. Likewise, for observations belonging to the cluster C2, their circumferences at 1.3 m from the ground will stretch from 109.9 and 117.4 cm. Their Pilodyn penetration depth will oscillate 23.88 and 24.35 mm. Therefore, Z1 will fluctuate from -2.135 to -0.562. Regarding cluster C3, their circumferences at 1.3 m from the ground will stretch from 91.1 and 106.7 cm. Their Pilodyn penetration depth will oscillate 26.24 and 28.69 mm. Therefore, Z1 will fluctuate from -3.384 to 1.007.

In contrast, concerning function 2, the individuals being part cluster C1, for the same values previously reported of the circumference at 1.3 m from the ground and the Pilodyn penetration depth, its Z2 will fluctuate from -0.528 to 0.055. In the same way, for individuals from cluster C2, with respect to the same values of the circumferences at 1.3 m from the ground the Pilodyn penetration depth, its Z2 will vary from -2.696 to -2.165. Concerning cluster C3, as for the circumferences at 1.3 m from the ground and the Pilodyn penetration depth its Z2 will fluctuate from 0.797 to 1.098.

In short, the individuals belonging to cluster C2 whose the discrimination scores Z1 and Z2 will fluctuate from -2.135 to -0.562 and from -2.696 to -2.165, respectively, will express low Pilodyn penetration depth and thus high basic wood density.

### Conclusion

We formulated the assumption that at least one cluster, among those evidenced, expresses low Pilodyn penetration depth, and thus shows high wood density. Effectively, cluster 2 consisting of Origins 2 and 9 recorded small Pilodyn penetration depth. Moreover, the variability of 16 Origins was structured into 3 clusters. As previously announced, the best cluster is the 2. The circumference at 1.3 m from the ground and the Pilodyn penetration depth are the variables containing sufficient information allowing the complete discriminating of clusters. The linear discriminant model provided 2 equations. These are  $Z1 = -38.111 + 0.761 \cdot \text{Pilo} + 0.162 \cdot \text{Circ1.3}$  and  $Z2 = -3.664 + 0.546 \cdot \text{Pilo} - 0.105 \cdot \text{Circ1.3}$ . They will allow the predicting of membership cluster of a new individual by using its values of the circumference at 1.3 m from the ground and the Pilodyn penetration depth.

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