**Leaf density, adult vegetative vigor and flushing intensity as relevant criteria for evaluating drought resistance of cocoa trees (Theobroma cacao L.)**

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ABSTRACT

In Côte d'Ivoire, one of the most recurrent manifestations of climate change results in long periods of drought lasting more than four consecutive months in the most-affected cocoa production areas. These droughts compromise cacao establishment, productivity and quality, which in turn threaten the longer-term sustainability of Ivorian cocoa farming. To address this constraint, one of the areas of research explored by breeders, is the identification of relevant criteria to assess the resistance of cocoa trees to drought, as a means to developing more climate-resilient genotypes. The purpose of this study is to show how adult vegetative vigor, leaf density and flushing intensity have proven to be relevant criteria for evaluating the resistance of cocoa trees to drought. A trial involving four agro-climatic zones (Bouaflé, Abengourou, Divo and Soubré), two of which experience significant rainfall deficits (Bouaflé and Abengourou), was set up in Côte d'Ivoire. The plant material, planted in two plots per zone, was made up of 15 CNRA families common to each agro-climatic zone and 10 to 15 free progenies, selected in each zone by the cocoa producers for their superior agronomic and technological performance. Eleven criteria were used to evaluate the plant material: i) vegetative vigor measured by the diameter at the collar; ii) trunk circumference at 130 cm above the ground; iii) tree height; iv) foliage density; v) leaf density; vi) flush intensity; vii) drought-sensitivity score ; viii) total number of cherelles per tree; ix) cherelle wilt rate; x) cumulative potential production (2015 to 2018), and xi) bean weight (weight of 100 dry cocoa beans).

The results showed a highly significant zone x family interaction (probability < 0.0001) for all the traits studied. In particular, six hybrid families were ranked in the top ten across all study areas, indicating resilience in the more challenging agro-climatic zones. Of these eleven criteria, those having best characterized the six families thus selected are, in decreasing order of importance: ‘i) leaf density; ii) vegetative vigor and iii) flush intensity. The use of these three criteria in the selection of drought-resilient plant material is envisaged.

**Keywords**: drought resistance, cacao breeding, relevant criteria

# Introduction

The cocoa tree (Theobroma cacao L.) is a perennial plant of great economic importance cultivated in tropical regions of the world (Bereau et al., 1992). Formerly classified in the Sterculiaceae family, Theobroma cacao L. is currently classified in the Malvaceae family (Alverson et al., 1999). It is cultivated for its seeds which, when fermented and dried, give merchantable cocoa, the raw material used for the manufacture of chocolate. Côte d'Ivoire is the world's leading producer with a production of 2,200,000 tons in 2019, which represents 40% of world supply (ICCO, 2020).

Despite its remarkable performance, Ivorian cocoa farming is marked by several production constraints affecting the productivity of orchards. These include the ageing of the orchard, the predominant use of unimproved plant material, the decline in soil fertility, strong parasitic pressure from mirids, brown pod rot and swollen shoot disease (Tahi et al., 2010; Guiraud et al., 2021; Trebissou et al., 2021).

In addition to these numerous constraints, which are already a significant burden on the budget of cocoa producers, climate change has been added in recent decades, characterized by extreme climatic variations that disrupt the seasons (Brou 2005). The most recurrent manifestation of this phenomenon in Côte d'Ivoire is long periods of drought lasting more than four consecutive months in the most affected production areas, making certain cocoa growing regions increasingly unfavorable (Kassin, 2009). These events result in failures in cocoa farm establishment, low orchard productivity and poor product quality.

In the current context of Côte d'Ivoire, where extensive and shifting agriculture cannot continue due to the depletion of forest reserves, it is necessary for the CNRA to take into account the criterion of drought resistance in its cocoa genetic improvement program. In this perspective, WCF and ECA-CABISCO-FCC initiated through Bioversity, the project entitled "An integrated approach to improve the efficiency and resilience of cocoa trees to climate change through better use of cocoa genetic resources" in which CNRA participated. One of the objectives of the work carried out in Côte d'Ivoire by the CNRA was to determine relevant criteria for evaluating the resistance of cocoa trees to drought. The work presented in this paper is part of this framework.

# Material and Methods

- Presentation of the study areas

Four study areas were considered (Figure 1): Abengourou and Bouaflé considered as areas with deficient rainfall and Divo and Soubré considered as areas with normal rainfall.

- Plant material

The plant material consisted of 15 CNRA hybrid families with potentially high yields common to the four zones (Table 1) and 10 to 15 free progenies selected by the producers for their agronomic and technological performance. In each trial plot, each family or free progeny was represented by 10 to 12 useful plants.

Previous work by Tahi et al. (2019) showed that six of the fifteen (15) CNRA hybrid families (F1, F2, F5, F10, F14, and F15) were found to be best adapted to the four (4) agro-climatic zones. These families were used as controls adapted to both rainfed and rainfed zones.

- Methods

- Experimental design

The experimental design is a split splot with two replications. The first factor is the zone with four levels: Abengourou, Bouaflé, Divo and Soubré. The second factor is the CNRA hybrid families with 15 levels: F1, F2, F3, F4, F5, F6, F7, F8, F9, F10, F11, F12, F13, F14 and F15. The 15 families were common to all study areas. Each plot had two outlying border lines outside the trial. The lines were 3 m apart and the trees on the line were 2.5 m apart.

- Measured parameters

Eleven observation criteria were evaluated to determine the relevant criteria for selecting drought resistant cocoa trees (Table 2, near here).

- Statistical analysis of the data

Data were subjected to analysis of variance with SAS 9.4 software (SAS Institue, 2018). Means were separated by the Student-Newman-Keuls test at the 5% threshold.

# Results and Discussion

- Results

Comparison of the four zones for the eleven cocoa tree evaluation criteria for drought resistance.

Observations were made on the eleven criteria previously presented. For all of these criteria, analysis of variance showed a significant difference (P < 0.001) between zones with a significant zone x family interaction (Table 3, near here). This suggests that the ranking of families varies across zones.

The Soubré zone had the best vegetative development on average for tree diameter (19 cm), girth (46.2 cm) and height (5.5 m). Cocoa trees in the Abengourou zone had low averages for diameter at 30 cm from the ground (13 cm). The Bouaflé zone recorded low averages for tree height (4.1m) and circumference (34.3 cm) at 130 cm of the cocoa trees. The Divo zone has on average the best morpho-physiological development of cocoa trees for Dfrond (2.8), Dfol (2.8) and Intflush (1.5), but the cocoa trees in this zone have low scores for sensitivity to drought (0.6) Cocoa trees in the Abengourou and Soubré zones had similar low average fruiting density (1.4). Cocoa trees in the Soubré zone have on average low leaf density (1.4), low flush intensity (0.7) and a high average drought sensitivity score (2.3).

Cocoa trees in the Divo zone produced on average the highest total number of cherelles (21.8) and low rates of cherelles willtées (0.3). The Abengourou zone produced fewer pods per tree (63.4). The highest average weight of one hundred marketable cocoa beans (100 MF) was observed in the Divo zone cocoa trees (137 g), and the Abengourou zone cocoa trees obtained low averages of 100 FM weight (119.8 g).

Comparison of the 15 hybrid families by production zone for eleven criteria for evaluating the resistance of cocoa trees to drought

Abengourou zone

With the exception of girth, flush intensity, total number of cherries and production potential, the analysis of variance showed a significant difference between families for all other cocoa tree evaluation criteria for drought resistance (Table 4, near here). In this area, the best families were:

- F2 (15.62 cm), F14 (15.37 cm) and F10 (14.31cm) for diameter at 30 cm from the ground;

- F10 (6.5 m) and F14 (6.00 m) for the height of cocoa trees;

- F8 (2.00) and F10 (1.97) for leaf density;

- F8 (2.02), F10 (1.71) and F2 (1.73) for foliage density;

- F12 (1.53), F11 (1.68), F3 (1.71), F2 (1.29) and F14 (1.26) for leaf drought sensitivity score;

- F8 (0.29), F7 (0.24) and F12 (0.27) for the rate of wilted cherelles;

- F2 (165.16 g), F8 (135 g), F11 (127.8 g), F1 (126.5 g) for the weight of 100 cocoa beans.

Bouaflé zone

With the exception of the intensity of flushes, the analysis of variance showed a significant difference between families for all the other criteria for evaluating cocoa trees for resistance to drought (Table 5). In this area, the best families were:

- F8 (17.33 cm), F6 (15.19 cm) and F2 (14.27cm), F15 (14.26) for diameter at 30 cm from the ground;

- F13 (44.12 cm), F14 (46.85 cm), F10 (41.38 cm) for the circumference at 130 cm from the ground;

- F10 (4.88 m), F11 (4.43 m) and F4 (4.14 m) for the height of cocoa trees;

- F8 (2.00 a), F10 (1.97 a), F9 (1.9 ab) and F14 (1.73 ab) for leaf density ;

- F8 (2.02), F2 (1.73) and F10 (1.71) for foliage density;

- F2 (1.29), F7 (1.26), F12 (1.53) for leaf drought sensitivity score;

- F14 (18.85) and F3 (20.05) for the number of total cherelles;

- F8 (0.21) and F10 (0.20) for the rate of wilted cherelles.

Soubré zone

With the exception of diameter, leaf density, foliage density, flush intensity and total number of cherelles, the analysis of variance showed a significant difference between families for all other cocoa tree evaluation criteria for drought resistance (Table 6). In Soubré, the best families were :

- F10 (66.43 cm), F2 (49.95), F14 (62.5) for girth;

- F10 (6.91 m), F3 (6.41 m) for height;

- F5 (1.19 b) for drought sensitivity score;

- F5 (0.14 b) for wilted cherelle rate;

- F5 (135.33 g), F2 (130.33 g), F12 (179 g), F1 (130.3 g) for the weight of 100 cocoa beans.

Divo zone

The analysis of variance showed a significant difference between the families for all the cocoa tree evaluation criteria for drought resistance (Table 7). In this zone, the best families were :

- F14 (15.85 cm) and F15 (15.35 cm) for diameter at 30 cm above ground;

- F15 (40.30 cm) for circumference at 130 cm from the ground;

- F15 (5.45 m) for the height of the cocoa trees;

- F10 (3.15), F5 (3.14) and F15 (3.11) for leaf density;

- F15 (3.30) and F10 (3.23) for canopy density;

- F14 (1.75) and F15 (1.73) for flush intensity;

- F4 (0.13) and F13 (0.26) for leaf drought sensitivity score;

- F5 (33.97) for the number of total cherelles ;

- F6 (0.08) for the rate of wilted cherelles;

- F2 (190.17 g), F1 (162.26 g), F14 (159.87 g) for the weight of 100 cocoa beans.

Frequencies of occurrence of the 11 criteria for evaluating the resistance of cocoa trees to drought in the selection of six families of hybrids of the CNRA found to be resistant to drought

Table 8 below presents the frequencies of occurrence of each of the eleven (11) criteria in the selection of the six hybrid families found to be resistant to drought. The frequencies varied from 33.3 to 58.3%. We note frequencies of :

- 54.2 % for vigor ((58.3 + 41.7 + 62.5) /3) ;

- 10/24 (41.7 %) for foliage density;

- 11/24 (45.8 %) for leaf density;

- 13/24 (54.2 %) for flush intensity;

- 8/24 (33.3 %) for leaf sensitivity to drought;

- 14/24 (58.3 %) for total number of cherelles;

- 8/24 (33.3%) for the rate of wilted cherelles;

- 7/14 (50.0%) for production potential;

- 10/18 (55.5%) for the weight of 100 merchantable cocoa beans.

# Discussion

Fifteen families of CNRA hybrids planted in four agro-ecological zones, two of which have low rainfall (Bouaflé and Abengourou) and two of which have normal rainfall (Divo and Soubré), were evaluated for the eleven criteria presented. The aim of the study is to determine which of these eleven criteria are the most relevant for evaluating the resistance of cocoa trees to drought. To conduct this study, six of the fifteen hybrid families shown to be adapted to both rainfall-deficient and rainfall-normal areas (Tahi et al. 2019) were used to determine the most relevant criteria.

Comparison of the four production zones for each of the eleven criteria considered revealed significant differences between the four zones. With regard to cocoa tree vigor assessed by three criteria (cocoa tree diameter at 30 cm from the ground, tree circumference at 30 cm from the ground and tree height), it appeared that the Soubré zone recorded the most vigorous cocoa trees with an average of 19 cm. With regard to foliage density, leaf density and flush intensity, the Divo zone showed the best performance with averages of 2.8, 2.8 and 1.5 respectively. With regard to the trees' leaf sensitivity to drought, the number of total cherries, the rate of wilted cherries and the production potential of the trees assessed by the total number of healthy, eaten and rotten pods, the highest performances were recorded respectively in Divo (score of 0.6 for Notesech, 21.8 for Chetotal and 0.3 for Tchewilt) and in Bouaflé (135.8 pods) In terms of graining, assessed by the weight of 100 cocoa beans, the highest weight (137 g) was observed in Divo. Generally speaking, it appears that the best performance for most criteria was obtained in areas with normal rainfall.

The analysis of variance showed that for all criteria, the zone x family interaction was highly significant, indicating that the ranking of families varies by production zone for each criterion. This means that within a given production area and for each criterion, the hybrid families can be ranked from the best performing to the worst performing. It can thus be seen that among the hybrid families showing the best performance for each evaluation criterion, most of the six families shown to be adapted to the four agro-climatic zones (F1, F2, F5, F10, F14 and F15) are cited. This result thus confirms the resilience of the six hybrid families as revealed by the work of Tahi et al. (2019). Thus, determining the relevant criteria for assessing the resilience of The study of the frequencies of occurrence of each evaluation criterion in the selection of the six families of hybrids most adapted to the different agro-climatic zones highlights frequencies varying from 33.3% to 58.3%.

The study of the frequencies of appearance of each evaluation criterion in the selection of the six families of hybrids best adapted to the different agro-climatic zones highlights frequencies varying from 33.3% to 58.3% for all the plant material taken simultaneously in the four zones where the families were planted. Of the eleven (11) criteria studied, the six (6) with the highest frequencies of occurrence were, in decreasing order of values, the total number of cherries (Chetot) with 58.3%, the weight of 100 cocoa beans (P100F) with 55. 5%, flush intensity (Intflush) and vigor with 54.2%, production potential (Totcab = total number of healthy, rotted and rotten pods produced per tree) with 50% and leaf density (Dfol) with 45.8%. However, of these six criteria, the ones that seem most relevant are vigor, flush intensity and leaf density. Indeed, although the criteria 'Chetot', 'P100F' and 'Totcab' presented high frequencies of occurrence, respectively 58.1, 55.5 and 50%, these were not retained as relevant because of the adult character that the tree must have before these criteria can be used for the selection of drought-resistant plant material. In contrast to the latter three criteria, the criteria considered relevant, namely tree vigor, leaf density and flush intensity, can be used at both the juvenile and adult stages for the assessment of drought resistance, which would be advantageous for considering early selection of drought-resistant plant material.

Regarding the proposed vigour as a relevant criterion, our results are in agreement with the work of Kouamé et al. (2021) who demonstrated that vegetative vigour of young cocoa trees under water stress was an indicator of tolerance to water stress. Our results also confirm those of Boulay (1998) and M'bo (2015) who showed that when faced with water stress induced under greenhouse conditions, the hybrid families that developed new leaf shoots and a greater leaf mass were those that had the best survival rates.

# Conclusion

Our work has shown that the cocoa planting area has an impact on the different criteria studied on the plant material. However, some families are able to adapt to different production zones. This was the case for the six families of hybrids used

in the determination of relevant criteria for evaluating the resistance of cocoa trees to drought. Although some criteria such as the total number of cherry trees 'Chetot', the seediness evaluated by the weight of 100 merchantable cocoa beans 'P100F' and the production potential of the tree 'Totcab' presented high frequencies of appearance in the selection of the six families of hybrids adapted to the four agro-climatic zones, They were less relevant than the criteria of vigour (measured by tree diameter, girth or height), flush intensity and leaf density, which have the potential to be used from the juvenile stage.

As an outlook, we should:

1. to confirm the efficient use of these three criteria at the juvenile stage by evaluating in greenhouse conditions, several hybrid families including as controls, the six families resilient to different agro-climatic zones. The confirmation of these three criteria at the young age as relevant in the evaluation of the resistance of cocoa trees to drought would be beneficial to the scientific community and especially to the producers who will know how to identify drought resistant plants from the nursery stage.
2. To research the drought resistance mechanisms of the six resilient families.

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# Figure and tables



**Divo**

Figure **1:** Location of the study areas (Abengourou, Bouaflé, Soubré and Divo) housing the test sites selected for the search for potential sources of drought resistance.

Table 1: CNRA hybrid families common to the 4 sites (Abengourou, Bouaflé, Divo and Soubré)

|  |  |
| --- | --- |
|  |  |
| Codes des familles | Généalogies (Femelle x Mâle) |
| F1 | UPA402 X UF676 |
| F2 | UPA409 X IFC1 |
| F3 | UPA608 X IFC412 |
| F4 | UPA413 X IFC1 |
| F5 | UPA603 x UF667 |
| F6 | UPA409 X POR |
| F7 | T85/799 X IFC15 |
| F8 | SCA6 X ICS1 |
| F9 | PA150 X IFC5 |
| F10 | T79/501 X IFC5 |
| F11 | IFC720 X ICS46 |
| F12 | IMC67 X IFC1 |
| F13 | MOQ413 X SCA6 |
| F14 | POR X T60/887 |
| F15 | PA150 X POR |

Table 2: List of eleven (11) criteria for evaluating the resistance of cocoa trees to drought

|  |  |  |
| --- | --- | --- |
| **Paramètres de vigueur** | **Paramètres de développement morpho physiologique** | **Paramètres de production** |
| **1**-le diamètre à 30 cm du sol (**Diam**) | **4** – la densité foliaire sur une échelle de notation de 1 à 4 (**Dfol**) | **8**- le nombre total de production de cabosse (**TOT**) par arbre après trois ans |
| **2**-la circonférence à 130 cm du sol (**Cir**) | **5-** la densité de frondaison sur une échelle de 1 à 4 (**Dfrond**) | **9**- le nombre total de cherelles (**Che Tot**) |
| **3**-la hauteur de l’arbre (**Haut**) | **6**- l’intensité de flush sur une échelle de 1 à 4 (**Intflush**) | **10**- le taux de chérelles wiltées (**Tchewilt**) |
|  | **7-** la sensibilité de perte des feuilles après une période de saisons sèches consécutive de 3 à 4 mois (**Notesech**) sur une échelle de 0 à 5 | **11**-le poids de 100 fèves de cacao marchand (**P100FM**) |

Table 3: Comparison of dry and wet areas for the eleven selection criteria for potentially drought-resistant cocoa trees

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Zones** | **Diam (cm)** | **Cir (cm)** | **Haut(m)** | **Dfrond** | **Dfol** | **Intflush** | **Notsech** | **Chetotal** | **Tchewilt** | **TotCab** | **P100FM** |
| Soubré | 19 a | 46.2 a | 5.5 a | 1.4 b | 1.4 c | 0.7 c | 2.3 a | 13.5 b | 0.5 a | \_ | 127.5 b |
| Divo | 13.9 b | 34.4 c | 4.7 c | 2.8 a | 2.8 a | 1.5 a | 0.6 c | 21.8 a | 0.3 c | 81.4 b | 137.0 a |
| Bouaflé | 13.3 bc | 34.3 c | 4.1 d | 1.5 b | 1.6 b | 0.9 b | 2.0 b | 12.8 b | 0.4 b | 135.8 a | \_ |
| Abengourou | 13.0 c | 40.5 b | 5.2 b | 1.4 b | 1.5 bc | 0.2 d | 1.8 b | 19.5 a | 0.4 b | 63.4 c | 119.8 c |
| **Moyenne** | 14.5 | 37.9 | 4.8 | 1.9 | 1.9 | 0.9 | 1.6 | 17.3 | 0.4 | 98.4 | 126 |
| **CV (%)** | 28.1 | 41.1 | 19 | 42.7 | 41.8 | 73.7 | 78.8 | 97.8 | 73.7 | 54.2 | 8.7 |
| **F** | 8.15 | 3.77 | 9.96 | 14.17 | 14.5 | 11.93 | 8.15 | 3.47 | 5.09 | 8.46 | 13.5 |
| ***P*** | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| ***Zone\*Famille*** | <0.0001 | 0.0006 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

Means with the same letter in a column are significantly identical according to the Newman & Keuls test at the threshold of 5%.

**Table 4:** Comparison of the 15 hybrid families in Abengourou for the eleven criteria for evaluating the resistance of cocoa trees to drought

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Famille** | **Diam (cm)** | **Cir (cm)** | **Haut (m)** | **Dfol** | **Dfrond** | **Intflush** | **Notsech** | **Chetotal** | **Tchewilt** | **Tot** | **P100FM** |
| F2 | 15.62 a | 43.88 a | 5.28 abcde | 1.70 abc | 1.73 ab | 0.07 a | 1.29 b | 29.55 a | 0.37 ab | 60.8 a | 165.16 a |
| F14 | 15.37 a | 46 a | 6.00 ab | 1.73 abc | 1.42 abc | 0.12 a | 1.26 b | 22.76 a | 0.42 ab | 49.5 a | 127 bc |
| F10 | 14.31 ab | 36.63 a | 6.2 a | 1.97 a | 1.71 ab | 0.27a | 2.06 ab | 24.94 a | 0.34 ab | 65.9 a | 115.33 cd |
| F8 | 14.03 ab | 46.75 a | 5.88 abc | 2.00 a | 2.02 a | 0.36 a | 1.93 ab | 13.7 a | 0.29 b | 54.1 a | 135 b |
| F7 | 13.91 ab | 44.05 a | 5.36 abcde | 1.65 abc | 1.41 abc | 0.12 a | 1.26 b | 19.61 a | 0.24 b | 62.9 a | 125.35 bc |
| F9 | 13.52 ab | 40.05 a | 5.1 bcde | 1.9 ab | 1.67 abc | 0.32 a | 2.03 ab | 26.55 a | 0.65 a | 67.4 a | 103.58 d |
| F4 | 12.65 ab | 40.00 a | 5.77 abcd | 1.2 abc | 1.3 abc | 0.12 a | 2.03 ab | 19.4 a | 0.39 ab | 54.1 a | 79.33e |
| F15 | 12.43 ab | 37.37 a | 5.55 abcde | 1.41 abc | 1.20 bc | 0.07 a | 2.78 a | 16.88 a | 0.43 ab | 70.9 a | 118.91bcd |
| F12 | 12.52 ab | 42.16 a | 4.8 cde | 1.55 abc | 1.41 abc | 0.08 a | 1.53 b | 20 a | 0.27 b | 45.7 a | 124.02 bc |
| F13 | 12.15 ab | 39.5 a | 4.62 e | 1.11 bc | 1.15 bc | 0.04 a | 2.04 ab | 13 a | 0.50 ab | 59.4 a | 115.33 cd |
| F5 | 12.09 ab | 41.29 a | 4.98 bcde | 1.62 abc | 1.32 abc | 0.33 a | 2.11 ab | 20.52 a | 0.45 ab | 44 a | 104.83 d |
| F6 | 11.95 ab | 35.61 a | 4.57 e | 0.97 c | 1.33 abc | 0.38 a | 2.07 ab | 10.94 a | 0.45 ab | 46.6 a | 114.41cd |
| F11 | 11.9 ab | 36.53 a | 4.68 de | 1.1 bc | 1.15 bc | 0.18 a | 1.68 ab | 18.33 a | 0.48 ab | 49.6 a | 127.83 bc |
| F3 | 11.45 b | 41.84 a | 4.65 e | 1.17 abc | 1.27 abc | 0.25 a | 1.71 ab | 19.31 a | 0.37 ab | 65.3 a | 112.66 cd |
| F1 | 10.82 b | 36.66 a | 4.94 bcde | 1.03 bc | 0.88 c | 0.03 a | 2.40 ab | 17.26 a | 0.37 ab | 59.9 a | 126.5 b |
| Moyenne | 12.99 | 40.52 | 5.23 | 1.48 | 1.41 | 0.2 | 1.48 | 19.5 | 0.41 | 57.01 | 119.85 |
| cv | 24.62 | 36.86 | 19.12 | 51.11 | 49.64 | 208 | 29.03 | 91.17 | 70.19 | 38.26 | 8.43 |
| F | 3.14 | 0.95 | 4.96 | 3.96 | 2.94 | 1.4 | 2.47 | 1.48 | 2.21 | 0.95 | 19.84 |
| *p* | 0.0002 | 0.5 | <0.0001 | <0.0001 | 0.0004 | 0.15 | 0.002 | 0.12 | 0.0084 | 0.5 | <0.0001 |

Les moyennes avec la même lettre dans une colonne sontsignificativement identiques selon le test de Newman & Keuls au seuil de 5.

**Table 5:** Comparison of the 15 families of hybrids in Bouaflé for the eleven criteria for evaluating the resistance of cocoa trees to drought

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Famille** | **Diam** | **Cir** | **Haut** | **Dfol** | **Dfrond** | **Intflush** | **Notsech** | **Chetotal** | **Tchewilt** | **Tot** |
| F8 | 17.33 a | 23.61 c | 3.76 b | 2.00 a | 2.02 a | 0.36 a | 1.93 ab | 9.46 ab | 0.21 c | . |
| F6 | 15.19 ab | 28.78 bc | 4.04 b | 0.97 c | 1.33 abc | 0.38 a | 2.07 ab | 13.27 ab | 0.42 abc | 61.21 cd |
| F2 | 14.27 b | 33.48 abc | 4.01 b | 1.70 abc | 1.73 ab | 0.07 a | 1.29 b | 17.95 ab | 0.44 abc | 131 abc |
| F15 | 14.26 b | 33.61 abc | 4.27 ab | 1.41 abc | 1.20 bc | 0.07 a | 2.78 a | 15 ab | 0.48 abc | 143.43 abc |
| F11 | 13.92 bc | 35.61 abc | 4.43 ab | 1.1 bc | 1.15 bc | 0.18 a | 1.68 ab | 8.05 ab | 0.34 bc | 104.29 abcd |
| F4 | 13.30 bc | 31.70 abc | 4.14 b | 1.2 abc | 1.3 abc | 0.12 a | 2.03 ab | 11.91ab | 0.33 bc | 140.93 abc |
| F5 | 13.30 bc | 36.66 abc | 4.05 b | 1.62 abc | 1.32 abc | 0.33 a | 2.11 ab | 18 ab | 0.70 a | 89.36 bcd |
| F13 | 13.22 bc | 44.12 ab | 4.27 ab | 1.11 bc | 1.15 bc | 0.04 a | 2.04 ab | 10.09 ab | 0.37 bc | 190 a |
| F1 | 13.01 bc | 31.14 abc | 3.85 b | 1.03 bc | 0.88 c | 0.03 a | 2.40 ab | 8.04 ab | 0.40 abc | 106.14 abcd |
| F9 | 12.48 bc | 29.13 bc | 3.76 b | 1.9 ab | 1.67 abc | 0.32 a | 2.03 ab | 10.95 ab | 0.53 ab | 104.29 abcd |
| F7 | 12.6b c | 34.25 abc | 3.84 b | 1.65 abc | 1.41 abc | 0.12 a | 1.26 b | 6.44 b | 0.59 ab | 100.57 abcd |
| F14 | 12.44 bc | 46.85 a | 4.05 b | 1.73 abc | 1.42 abc | 0.12 a | 1.26 b | 18.85 a | 0.62 ab | 119.14 abcd |
| F10 | 12.37 bc | 41.38 ab | 4.88 a | 1.97 a | 1.71 ab | 0.27 a | 2.06 ab | 17.28 ab | 0.20 c | 146.93 abc |
| F3 | 11.90 bc | 32.78 abc | 3.9b | 1.17 abc | 1.27 abc | 0.25 a | 1.71 ab | 20.05 a | 0.56 ab | 176.64 ab |
| F12 | 11.53 bc | 38.88 abc | 3.68b | 1.55 abc | 1.41 abc | 0.08 a | 1.53 b | 16.5 ab | 0.43 abc | 35.29 d |
| **Moyenne** | 13.3 | 34.27 | 4.07 | 1.48 | 1.41 | 0.2 | 1.48 | 12.85 | 0.44 | 117.81 |
| **cv** | 24.62 | 43.76 | 17.98 | 51.11 | 49.64 | 207.97 | 29.03 | 87.29 | 63.03 | 61.86 |
| **F** | 3.36 | 2.57 | 2.54 | 3.96 | 2.94 | 1.4 | 2.47 | 3.16 | 4.22 | 4.56 |
| ***p*** | <0.0001 | 0.0018 | 0.002 | <0.0001 | 0.0004 | 0.15 | 0.0024 | <0.0001 | <0.0001 | <0.0001 |

**Table 6**: Comparison of the 15 families of hybrids in Soubré for the eleven criteria for evaluating the resistance of cocoa trees to drought

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Famille** | **Diam** | **Cir** | **Haut** | **Dfol** | **Dfrond** | **Intflush** | **Notsech** | **Chetotal** | **Tchewilt** | **P100FM** |
| F10 | 22.62 a | 60.43 a | 6.91 a | 1.10 a | 1.10 a | 0.71 a | 1.40 ab | 13 a | 0.69 a | 124.66 bc |
| F2 | 22.15 a | 49.95 ab | 4.90 bc | 1.35 a | 1.21 a | 1.00 a | 1.95 a | 8.71 a | 0.48 ab | 130.33 bc |
| F14 | 22 a | 62.5 a | 5.44 abc | 1.35 a | 1.35 a | 1.28 a | 1.38 ab | 9.42 a | 0.41 ab | 111.33 c |
| F9 | 21.5 a | 44.12 ab | 6.06 abc | 1.52 a | 1.70 a | 0.64 a | 1.43 ab | 17.23 a | 0.63 a | 123.66 bc |
| F12 | 19.94 a | 41.71 ab | 5.41 abc | 1.30 a | 1.23 a | 0.92 a | 1.51 ab | 23.23 a | 0.55 ab | 179 a |
| F8 | 19.59 a | 46.7 ab | 4.61c | 1.00 a | 1.23 a | 1.23 a | 1.50 ab | 11.38 a | 0.37 ab | 133 bc |
| F3 | 19.25 a | 24.66 b | 6.41 ab | 1.62 a | 1.78 a | 0.18 a | 1.58 ab | 13.18 a | 0.59 ab | 129.33 bc |
| F15 | 19.4 a | 54.9 ab | 5.59 abc | 1.86 a | 1.75 a | 1.00 a | 1.61 ab | 14.66 a | 0.41 ab | 131.33 bc |
| F11 | 19.02 a | 44.37 ab | 5.72 abc | 1.21 a | 1.42 a | 0.71 a | 1.65 ab | 16.92 a | 0.63 a | 112 c |
| F4 | 18.44 a | 45.16 ab | 5.36 abc | 1.54 a | 1.36 a | 0.81 a | 1.84 ab | 10.45 a | 0.56 ab | 117 bc |
| F5 | 16.75 a | 47.09 ab | 5.27 bc | 1.22 a | 1.11 a | 0.66 a | 1.19 b | 13.33 a | 0.14 b | 135.33 b |
| F6 | 16.76 a | 40.92 ab | 5.62 abc | 1.42 a | 1.5 a | 0.85 a | 1.83 ab | 16.5 a | 0.78 a | 121.66 bc |
| F7 | 16.14 a | 51.11 ab | 5.47 abc | 1.73 a | 1.73 a | 0.76 a | 1.73 ab | 12.23 a | 0.42 ab | 116.66 bc |
| F13 | 15.1 a | 39.87 ab | 4.86 abc | 1.28 a | 1.35 a | 0.42 a | 1.94 a | 8 a | 0.38 ab | 117.33 bc |
| F1 | 15.1 a | 45.21 ab | 5.15bc | 0.85 a | 0.8 a | 0.3 a | 1.30 ab | 10.2 a | 0.33 ab | 130.33 bc |
| **Moyenne** | 19.02 | 46.21 | 5.53 | 1.38 | 1.41 | 0.75 | 2.36 | 13.52 | 0.51 | 127.53 |
| **cv** | 35.41 | 54.35 | 22.28 | 64.64 | 66.02 | 118.37 | 66.9 | 118.61 | 59.58 | 5.9 |
| **F** | 1.72 | 1.75 | 2.87 | 1.24 | 1.19 | 1.46 | 2.13 | 0.82 | 2.55 | 13.87 |
| ***p*** | 0.05 | 0.05 | 0.0006 | 0.25 | 0.28 | 0.12 | 0.0124 | 0.65 | 0.0025 | <0.0001 |

**Table 7:** Comparison of the 15 families of hybrids at Divo for the eleven criteria for evaluating the resistance of cocoa trees to drought

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Famille** | **Diam** | **Cir** | **Haut** | **Dfol** | **Dfrond** | **Intflush** | **Notsech** | **Chetotal** | **Tchewilt** | **Tot** | **P100FM** |
| **F14** | 15.85 a | 35.1 ab | 4.39 b | 2.95 a | 2.87 abcd | 1.75 a | 0.68 ab | 18.12 bc | 0.17 bcd | . | 159.87 b |
| **F15** | 15.35 ab | 40.30 a | 5.45 a | 3.11 a | 3.30 a | 1.73 a | 0.4 ab | 29.5 ab | 0.23 abcd | . | 149.75 bc |
| **F2** | 14.74 ab | 36.31 ab | 4.58 b | 2.79 a | 2.79 abcd | 1.54 a | 0.4 ab | 17.5 bc | 0.17 bcd | . | 190.17 a |
| **F5** | 14.44 ab | 35.89 ab | 4.84 ab | 3.14 a | 3.08 abc | 1.54 a | 0.72 ab | 34.97 a | 0.36 ab | 201.25 a | 115.35 de |
| **F1** | 14.35 ab | 34.18 ab | 4.63 b | 3.08 a | 3.00 abcd | 1.54 a | 1.2 a | 21.56 abc | 0.28 abcd | . | 162.26 b |
| **F10** | 14.23 ab | 34.61 ab | 4.99 ab | 3.15 a | 3.23 ab | 1.53 a | 0.8 ab | 23.84 abc | 0.17 bcd | . | 122.62 cde |
| **F12** | 13.78 ab | 34.18 ab | 4.88 ab | 2.63 a | 2.47 cd | 1.47 a | 0.64 ab | 14.23 bc | 0.28 abcd | 41.58 b | 139.03 bcde |
| **F8** | 13.77 ab | 33.87 b | 4.79 ab | 2.91 a | 2.81 abcd | 1.45 a | 0.36 ab | 20.10 abc | 0.28 abcd | 89 b | 126.07 cde |
| **F6** | 13.57 ab | 32.41 b | 4.81 ab | 1.36 b | 1.36 e | 1.27 ab | 0.85 ab | 10.45 c | 0.08 d | 60.58 b | 130.91 bcde |
| **F4** | 13.33 ab | 34.01 ab | 4.88 ab | 2.67 a | 2.70 abcd | 1.45 a | 0.13 b | 13.73 bc | 0.27 abcd | 28.75 b | 142.96 bcd |
| **F3** | 12.81 b | 32.06 b | 4.49 b | 2.81 a | 2.68 abcd | 1.39 a | 0.55 ab | 27.55 ab | 0.30 abc | 93 b | 135.69 bcde |
| **F13** | 12.69 b | 35.76 ab | 4.93 ab | 2.5 a | 2.5 bcd | 0.91 b | 0.26 b | 30.75 ab | 0.14 bcd | 89.17 b | 131.41 bcde |
| **F9** | 9.9 c | 26.41 c | 3.64 c | 1.81 b | 2.27 d | 0.90 b | 0.79 ab | 15.18 bc | 0.41 a | 34.67 b | 107.7 e |
| **F7** | . | . | . | . | . | . | 0.73 ab | . | . | . | . |
| **F11** | . | . | . | . | . | . | 0.70 ab | . | . | . | . |
| **Moyenne** | 13.9 | 34.42 | 4.76 | 2.81 | 2.78 | 1.47 | 0.59 | 21.79 | 0.26 | 79.75 | 137 |
| **cv** | 22.53 | 24.1 | 16.57 | 29.24 | 27.9 | 40.41 | 171.31 | 79.88 | 76.85 | 68.62 | 10.34 |
| **F** | 3.71 | 2.69 | 4.91 | 6.05 | 6.5 | 2.79 | 2.18 | 4.76 | 3.21 | 12.35 | 8.19 |
| ***p*** | <0.0001 | 0.0002 | <0.0001 | <0.0001 | <0.0001 | 0.0012 | 0.0079 | <0.0001 | 0.0002 | <0.0001 | <0.0001 |

**Table 8:** Frequency of occurrence of each evaluation criterion in the selection of six hybrid families adapted to different agro-climatic zones

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Vigueur** | | | | | | | | | | | |  | | | |  | | | |  | | | |  | | | |  | | | |  | | | |  | | | |  | | | |
|  | | | |
|  | **Diam** | | | | **Haut** | | | | **Cir** | | | | **Dfrond** | | | | **Dfol** | | | | **Intflush** | | | | **Notsech** | | | | **Chetot** | | | | **TChwillt** | | | | **Totcab** | | | | **P100F** | | | |
|
| **Familles** | **A** | **B** | **D** | **S** | **A** | **B** | **D** | **S** | **A** | **B** | **D** | **S** | **A** | **B** | **D** | **S** | **A** | **B** | **D** | **S** | **A** | **B** | **D** | **S** | **A** | **B** | **D** | **S** | **A** | **B** | **D** | **S** | **A** | **B** | **D** | **S** | **A** | **B** | **D** | **S** | **A** | **B** | **D** | **S** |
| **F1** |  |  | **X** | |  |  |  |  |  |  |  |  |  |  | **x** |  |  |  | **x** |  |  | **x** | **x** |  | **x** |  | **x** |  |  |  | **x** |  |  |  | **x** |  |  |  |  |  | **x** |  | **x** | **x** |
| **F2** | **X** | **X** | **X** | **X** |  |  |  |  | **x** |  | **x** | **x** | **x** |  |  |  | **x** |  |  |  |  |  | **x** | **x** |  |  |  |  | **x** | **x** |  |  |  |  |  |  | **x** | **x** |  |  | **x** |  | **x** |  |
| **F5** |  |  | **X** | |  |  | **X** | |  | **x** | **x** | **x** |  |  | **x** |  |  |  | **x** |  | **x** |  | **x** |  | **x** |  | **x** |  | **x** | **x** | **x** | **x** | **x** | **x** | **x** |  |  |  | **x** |  |  |  |  | **x** |
| **F10** | **X** | | **X** | **X** | **X** | **X** | **X** | **X** |  | **x** | **x** | **x** | **x** |  | **x** |  | **x** | **x** | **x** |  | **x** |  | **x** |  | **x** |  | **x** |  | **x** | **x** | **x** |  |  |  |  | **x** | **x** | **x** |  |  |  |  |  |  |
| **F14** | **X** | | **X** | **X** | **X** | |  |  | **x** | **x** | **x** | **x** | **x** | **x** | **x** |  | **x** | **x** | **x** |  |  | **x** | **x** | **x** |  |  |  |  | **x** | **x** |  |  |  | **x** |  |  |  |  |  |  | **x** |  | **x** |  |
| **F15** |  | **X** | **X** | | **X** | **X** | **X** | **X** |  |  | **x** | **x** |  |  | **x** | **x** |  |  | **x** | **x** |  |  | **x** | **x** | **x** | **x** |  |  |  |  | **x** | **x** | **x** | **x** |  |  |  | **x** | **x** |  |  |  | **x** | **x** |
| **Total** | **14** | | | | **10** | | | | **15** | | | | **10** | | | | **11** | | | | **13** | | | | **8** | | | | **14** | | | | **8** | | | | **7** | | | | **10** | | | |
| **Fréquences** | **14/24** | | | | **10/24** | | | | **15/24** | | | | **10/24** | | | | **11/24** | | | | **13/24** | | | | **8/24** | | | | **14/24** | | | | **8/24** | | | | **7/14** | | | | **10/18** | | | |
| **(58.3 %)** | | | | **(41.7 %)** | | | | **(62.5 %)** | | | | **(41.7 %)** | | | | **(45.8 %)** | | | | **(54.2 %)** | | | | **(33.3 %)** | | | | **(58.3 %)** | | | | **(33.3 %)** | | | | **(50.0 %)** | | | | **(55.5 %)** | | | |
| **54.2 %** | | | | | | | | | | | | **41.7 %** | | | | **45.8 %** | | | | **54.2 %** | | | | **33.3 %** | | | | **58.3 %** | | | | **33.3 %** | | | | **50.0 %** | | | | **55.5 %** | | | |

**A** : Abengourou ; **B** : Bouaflé ; **D** : Divo ; **S**: Soubré