CENTRE NATIONAL DE RECHERCHE AGRONOMIQUE

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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Presentation outline

- INTRODUCTION
- MATERIELS & METHODES
- RESULTATS
- CONCLUSION & PERSPECTIVES

INTRODUCTION

Background

- **Cocoa bean = vital product for several producing countries**
- **Côte d'Ivoire = leader in the supply of cocoa beans**
  - Record production of 2,200,000 tons of cocoa in 2019 (40% of world supply)
  - Source of employment for 6,000,000 people

Context & justification

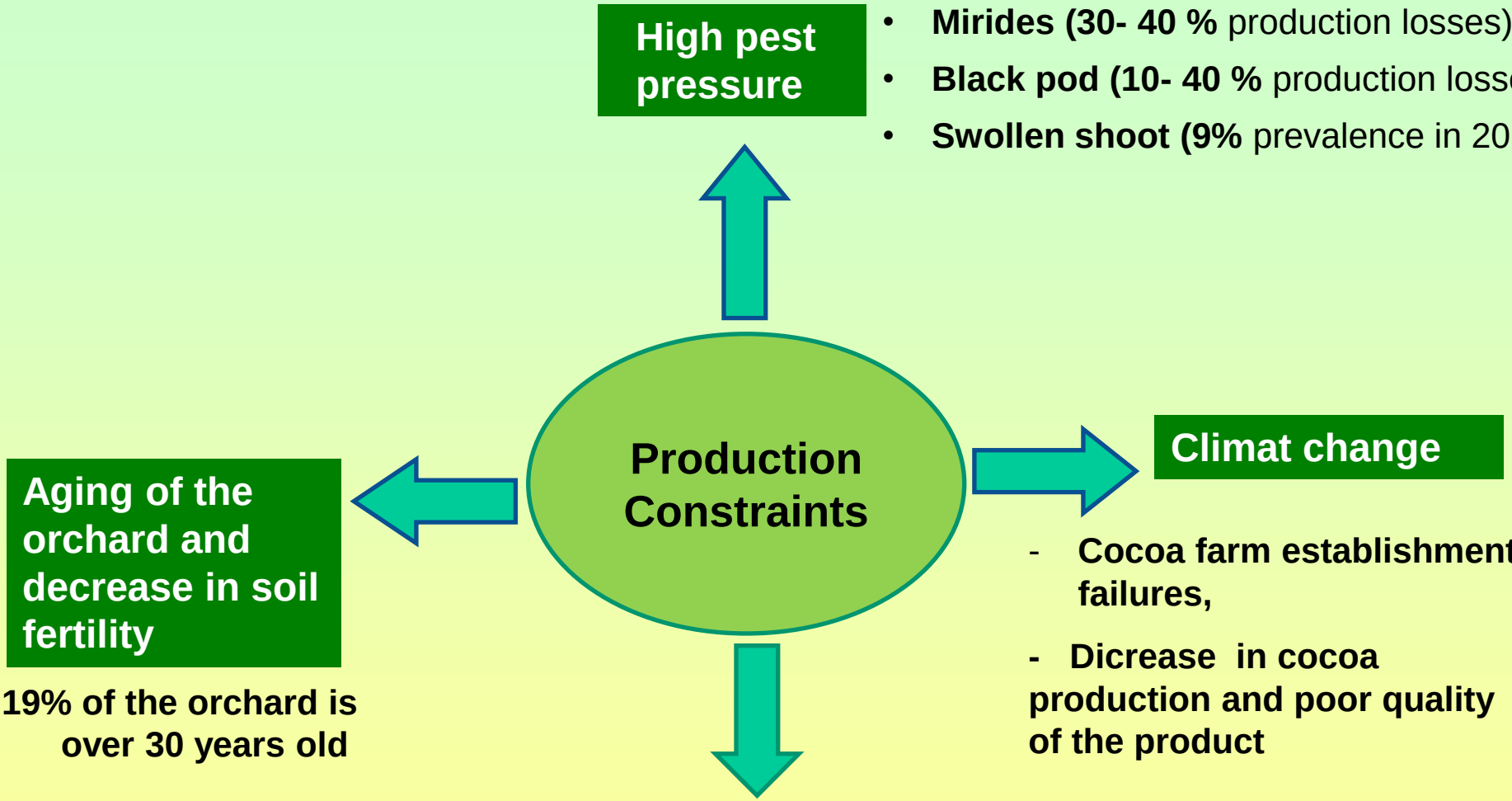


Fig. 1: Negatives effects of drought on orchard establishment and product quality (Bouaflé area in Côte d'Ivoire)

Destruction of a young cocoa farm, (Bouaflé in Fév., 2012)

Drying of pods

Accolement of the beans in a pod

Objectives

General objective

To improve cocoa productivity through the selection of high producing and drought resistant genotypes

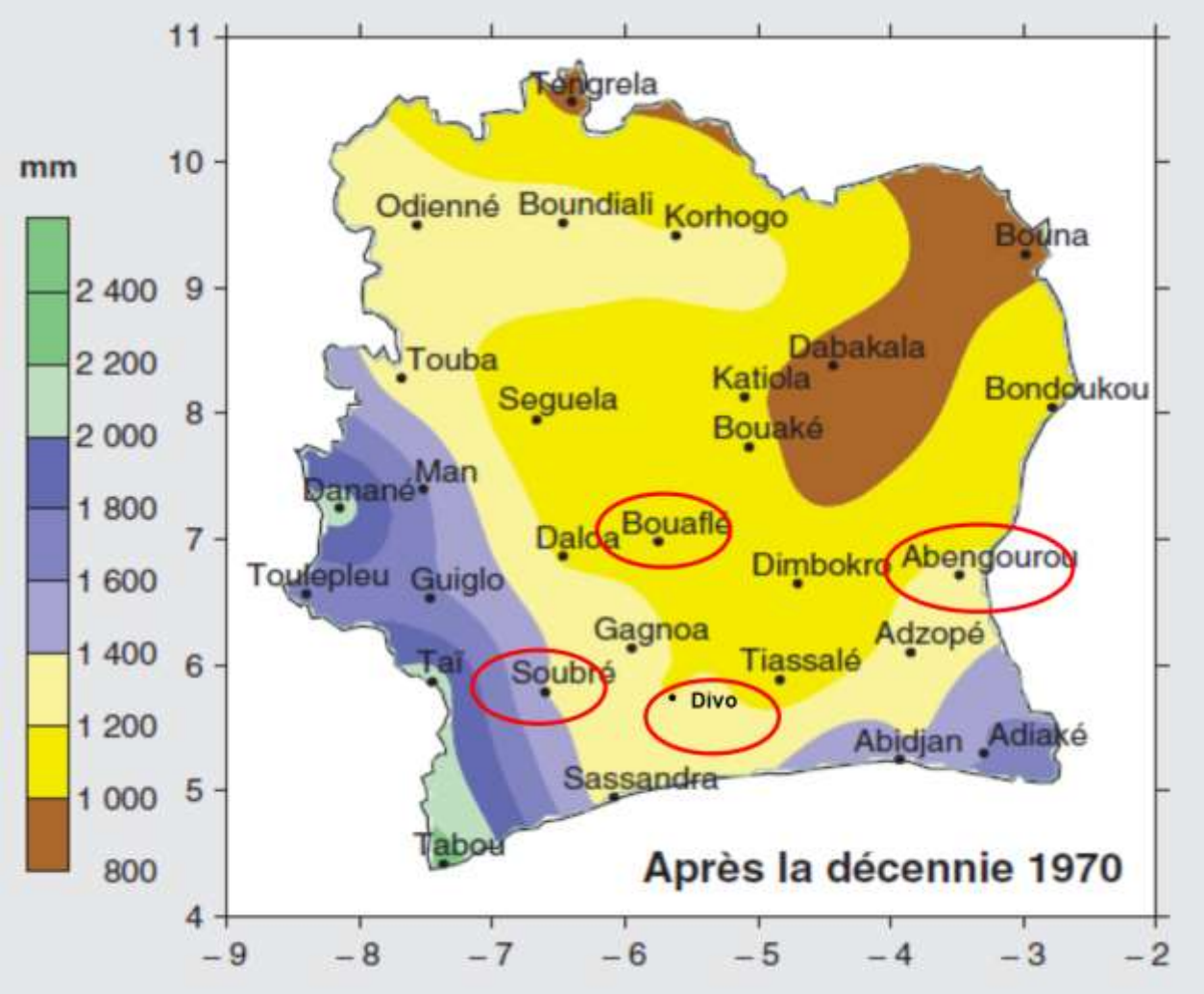
Specific Objective

To determine relevant criteria for the evaluation of the resistance of cocoa trees to drought

MATERIEL & METHODES

❑ Study areas

Study based on previous participatory selection trials involving 4 production areas (**CFC/ICCO/Bioversity project, 2004-2009); FIRCA project (2008-2011)**)



- **Bouaflé** et **Abengourou**: low rainfall areas (less than 1200 mm of rain with 3 to 4 consecutive months of drought)
- **Divo** et **Soubré**:areas with normal rainfall (1200 mm of rain on average per year)

MATERIEL & METHODS

- 15 hybrid families (F1 to F15) potentially high yielding (12 trees/family);
- 40 to 60 free progenies selected by producers for their superior agronomic performance;

N.B: Six of the 15 families (**F1, F2, F5, F10, F14, and F15**) used as **controls** in the search for relevant criteria for evaluating drought resistance because of their resilience to the 4 agro-climatic zones (***Tahi et al*., 2019)**

- **Experimental design:**

✓ 2 plots in each study area (split plot with 2 replicates);

✓ In each plot, 15 CNRA families planted at the same time as 10 to 15 free progenies proposed by the producers

MATERIAL & METHODS

- **Data collected (11 criteria)**

Vigor parameters	Morphological and physiological parameters	Production parameters
1. Trunk diameter at 30 cm from the ground (**Diam)**	**4.** Leaf density (**Dfol**) on a scale of 1 to 4	**8**. Total number of pods produced per tree (**TOT**) over 3 years
2. Circumference of the trunk at 130 cm from the ground (**Cir**)	**5.** Canopy density (**Dfrond**) on a scale of 1 to 4	**9**. Number of total sherds (**CheTot**)
3. Height of the tree (**Haut**)	**6.** Intensity of leaf flush on a scale of 1 to 4 (**Intflush**)	10. Rate of wilted sherds (**Tchewilt**)
	7. Sensitivity to leaf loss after a dry period of 3 to 4 consecutive months (**Notesech**)	11. Weight of 100 merchantable cocoa beans (**P100FM**)

- **Analyses statistiques:** S.A.S 9.4 (S.A.S Institute, 2018)

RESULTATS

Table 1 : Comparison of the 4 study areas for the eleven criteria for evaluating the resistance of cocoa trees to drough

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
Mean	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

Table 2 : Comparison of 15 families of hybrids 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	79.33 e
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

Table 3 : Comparison of 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 4 : Comparison of 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 5 : Comparison of 15 families of hybrids in **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 6: 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 (58.3 %)	10/24 (41.7 %)	15/24 (62.5 %)	10/24 (41.7 %)	11/24 (45.8 %)	13/24 (54.2 %)	8/24 (33.3 %)	14/24 (58.3 %)	8/24 (33.3 %)	7/14 (50.0 %)	10/18 (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

CONCLUSION & PERSPECTIVES

Conclusion

- Significant effect of the planting area on the different criteria for evaluating the resistance of cocoa trees to drought: **the performance of the plant material is generally higher in humid areas than in dry areas;**

- Confirmation of the drought resilience of six hybrid families (**F1, F2, F5, F10, F14 and F15);**

- Six evaluation criteria (Chetot, P100F, Intflush, Totcab, Dfol, and vig) showed the highest frequencies of occurrence**. However, the three most relevant criteria were Vig, Dfol and Intflush.**

Perspectives

- To confirm the efficient use of the three relevant criteria at the juvenile stage, which would allow producers to select drought-resistant cocoa trees themselves from the nursery stage;

- Search for drought resistance mechanisms in the 6 drought-resilient hybrid families.

Acknowledgements

CNRA, nous inventons aujourd'hui l'agriculture de demain.