ASSESSMENT AND HERITABILITY OF PRODUCTIVITY AND TOLERANCE LEVEL TO *PHYTOPHTHORA MEGAKARYA* IN TWO HYBRID POPULATIONS OF *THEOBROMA CACAO*

P.F. Djocgoue[1,2], C. Simo[1], H.D. Mbouobda[1], T. Boudjeko[3,4], D.J. Nankeu[1] and N.D. Omokolo[1]

[1]Laboratory of Plant Physiology, Department of Biological Sciences, Higher Teacher's Training College, P.O. Box 47, Yaounde, Cameroon
[2]Department of Plant Biology, Faculty of Science, P.O. Box 812, Yaounde, Cameroon
[3]Department of Biochemistry, Faculty of Science, P.O. Box 812, Yaounde, Cameroon
[4]Laboratory of Phytoprotection and Plant Valorisation, Biotechnology Centre Nkolbisson P.O. Box 3851, Messa Yaoundé, Cameroun

SUMMARY

The cocoa tree (*Theobroma cacao L.*) is a cash crop cultivated in humid tropical regions. The commercialization of cocoa seeds constitutes a major source of income to farmers in the producing countries. Nevertheless, a major limiting factor to the culturing of this plant in Cameroon is black pod disease caused by *Phytophthora megakarya.* The vulnerability of *T. cacao* to *P. megakarya* was assessed in two hybrid populations (F79: ♀T79/467×♂SNK13; F13: ♀SNK13×♂T79/467) through the daily measurement of the necrotic lesion on the pods after artificial inoculation. The parental and progeny productivity was also assessed through measurements of the weight of 100 cocoa seeds. Principal Component Analysis (PCA) of the necrotic lesion on the pods taking into consideration the development of necrosis during time showed that 95.73% and 94.48% of the total variability expressed by axes 1 and 2 enables the classification of the different genotypes into 4 and 5 groups for F79 and F13 families, respectively. In addition, ANOVA results indicated that necrotic surfaces showed a significant effect of day after inoculation and genotype to all the progeny ($P<0.001$). Heritability of the two reciprocal crossings is high (0.81 for F79 and 0.91 for F13) and does not show a significant difference, suggesting the absence of maternal effects in the developmental character of necrosis. The hybrids F7902, F7909, F7917, F7921, F7925, F7928, F1304, F1307, F1309, F1314, F1318, F1323 and F1325 showed a higher productivity and less development of necrosis than those of the best parents. They can thus be considered as the best genotypes. These results suggest that a large scale distribution of these genotypes to farmers will permit a short term improvement of cocoa yield in Cameroon.

Key words: cocoa, disease, tolerance, inheritance, yield.

Corresponding author: P.F. Djocgoue
Fax: +237.22237429
E-mail: pfdjocgoue@yahoo.com; djocgoue@uy1.uninet.cm

INTRODUCTION

Cocoa is a tropical forest plant with its diversity centre located in South America (Bailey *et al.*, 2005). It was introduced in Cameroon in 1892 by the Germans and is cultivated mainly for its seeds (cocoa beans). After fermentation and drying, the seeds are ready for commercialization and constitute a source of revenue for numerous small-scale farmers. The world production of cocoa beans has risen from 3.10 million tons in 2003 to 4.06 million tons in 2006. Africa alone is responsible for more than 70% of this production (Anonymous, 2006). In Cameroon, this production has increased from 145,000 tons in 2004 to 166,800 tons in 2006. This increase however remains below the world demand, which has been in a continuous rise of 4% during the last three decades (Békou and Cilas, 2006). There is therefore a need for cocoa-producing countries to develop innovative strategies that would permit increases in yields to meet with world demands. However, the cultivation of this plant is faced with numerous problems such as ageing of plantations, parasitic pressure and the insufficiency of genotypes selected for high productivity. Among the parasitic constraints, black pod disease caused by *Phytophthora megakarya*, causes significant losses worldwide. These losses globally attain 20 to 30%, but might reach 80% in some central African countries (Nyassé, 1992; Pokou *et al.*, 2008). In Cameroon, *P. megakarya* causes over 80% losses depending on the ecological zone (Nyassé, 1992; Berry and Cilas, 1994) which may reach 100% if no control measures are enforced (Despréaux *et al.*, 1988; Ndoumbe-Nkeng *et al.*, 2004). Even though the chemical control of black pod disease is currently effective, the use of tolerant and productive genotypes would be less expensive for agricultural practices, and above all, present no ecological problems related to the use of chemicals.

Two main groups of cocoa are known: the Criollo, less productive and more resistant to black pod disease, and Forestero, more productive and more sensitive to black pod disease. The groups differ mainly in the form of their pods. Another group, Trinitario, represents the hybrid form of the first two groups, first selected in

Trinidad before being distributed widely to other countries; Cameroon included (Eskes and Lanaud, 1997).

Field observation of cocoa pod invasion by *P. megakarya* have revealed the existence of partial genetically heritable tolerance (Despréaux *et al.*, 1989). In particular, observations of genotype performance under conditions of natural or artificial infection and inoculation tests on pods or leaves enabled the identification of tolerant genotypes (Nyassé *et al.*, 1995; Iwaro *et al.*, 1998; Nyassé *et al.*, 2002; Djocgoue *et al.,* 2006). World cocoa production is resulting mainly from hybrid genotypes. In fact, the most outstanding producing countries are those that use the highest hybrid rates in plot regeneration. This rate is 76% for Indonesia, 69.2% for Ivory Coast, 69% for Malaysia, 63.2%, 25.1% and 17.4% for Ghana, Cameroon and Ecuador, respectively. Thus, hybrid varieties are characterized by high productivity and environmental adaptation capacity due to the additive effect of parental genes and can be used on a large scale (Tahi *et al.*, 2000; Djocgoue *et al.*, 2006).

One of the main objectives for cocoa farming in Cameroon is the selection of genotypes less vulnerable to cocoa pod brown rot. The manifestation of a hybrid vigour for tolerance therefore stands out as a major factor for the identification of genotype performances (Nyassé, 1997; Djocgoue, 1998). Thus, the aim of the present study was to assess the productivity and tolerance levels of two hybrid families derived from the reciprocal crossing of T79/468xSNK13 to identify non-negligible resistance and/or productivity that could be used in the genetic improvement scheme of cocoa resistance to *P. megakarya*.

MATERIALS AND METHODS

Plant material. The plant material derived from the experimental station of the Cocoa Development Corporation (SODECAO) consisted of immature cocoa pods of two parental clones (the less tolerant and more productive SNK13, Trinitario group, the more tolerant and less productive T79/467, Forastero group) as well as their hybrid progenies organized within the F13 (♀SNK13×♂T79/467) and F79 (♀T79/467×♂SNK13) populations. The fungus was a local isolate of *P. megakarya* (TA121) obtained from the Research Institute for Agricultural Development (IRAD) at Nkolbisson (Yaounde).

Cocoa pods inoculation. Three-month-old pods were harvested, washed with tap water, sterilized with cotton immersed in 70° alcohol and replicated into three: (i) fresh pods; (ii) pods that had been scarified and inoculated with a sterilized agar disk; (iii) pods that had been scarified and inoculated with an agar disk containing *P. megakarya* mycelium (Djocgoue, 1998). The isolate of *P. megakarya* used was maintained through regular transfer on pea agar medium and used for the inoculation of the pods. The inoculation was carried out by the deposition of a 6 mm diameter agar disk containing mycelium on the scar obtained with a hand utensil. The scars were then covered with cotton that had been immersed in sterilized water. Pod inoculation was done in a dark culture room at 25°C.

Assessment of necrotic development and productivity. The development of necrosis and the weight of cocoa seeds was measured during three successive observations of cocoa trees. Data recorded in each visit consisted of: (i) measurement of the necrosis surface area done at 3, 4, 5 and 6 days post inoculation (dpi); (ii) measurement of the diameter of the more or less circular necrotic spots and calculation of their surfaces using Blaha and Lotode's formula (Blaha and Lotode, 1976); (iii) productivity, assessed by measuring the weights of 100 cocoa seeds of the different genotypes (Cilas, 1991).

Estimation of the heritability. For the different parameters measured, heritability was estimated according to Falconer (1974). This estimation considers the regression slope between means of parents and progeny.

Statistical analyses. Data on the evolution of necrotic surface and productivity are presented in the form of Means±SD, for at least three independent experiments. Analysis of variance (ANOVA) and Duncan tests were used to compare the susceptibility levels of the best progenies resulting from different crosses to compare hybrid vigour, using SPSS version 12. P value lower than 0.05 was considered significant. The principal component analysis (PCA) and the hierarchical classification were performed with SPAD version 4.1 windows software.

RESULTS

Evolution of necrotic surfaces. The development of necrosis on the pod surface was assessed in the 62 genotypes. Fresh pods and those previously scarified and inoculated with a sterile agar disk did not develop necrotic lesions. Pods that were scarified and inoculated with mycelium of *P. megakarya*, developed necrosis in all parental genotypes three dpi inoculation in 34% of those of the F79 and in 50% of those from the F13 populations. From the fourth day, the necrosis evolved regularly in all the inoculated genotypes till the sixth day (Fig. 1). The kinetics of this evolution was variable from one genotype to the next. Generally, for individuals of the F79 family, the size of necrosis varied between 2.21 cm^2 to 85.83 cm^2. Six dpi, the development of the necrosis was less marked in the F7902, F7903, F7907,

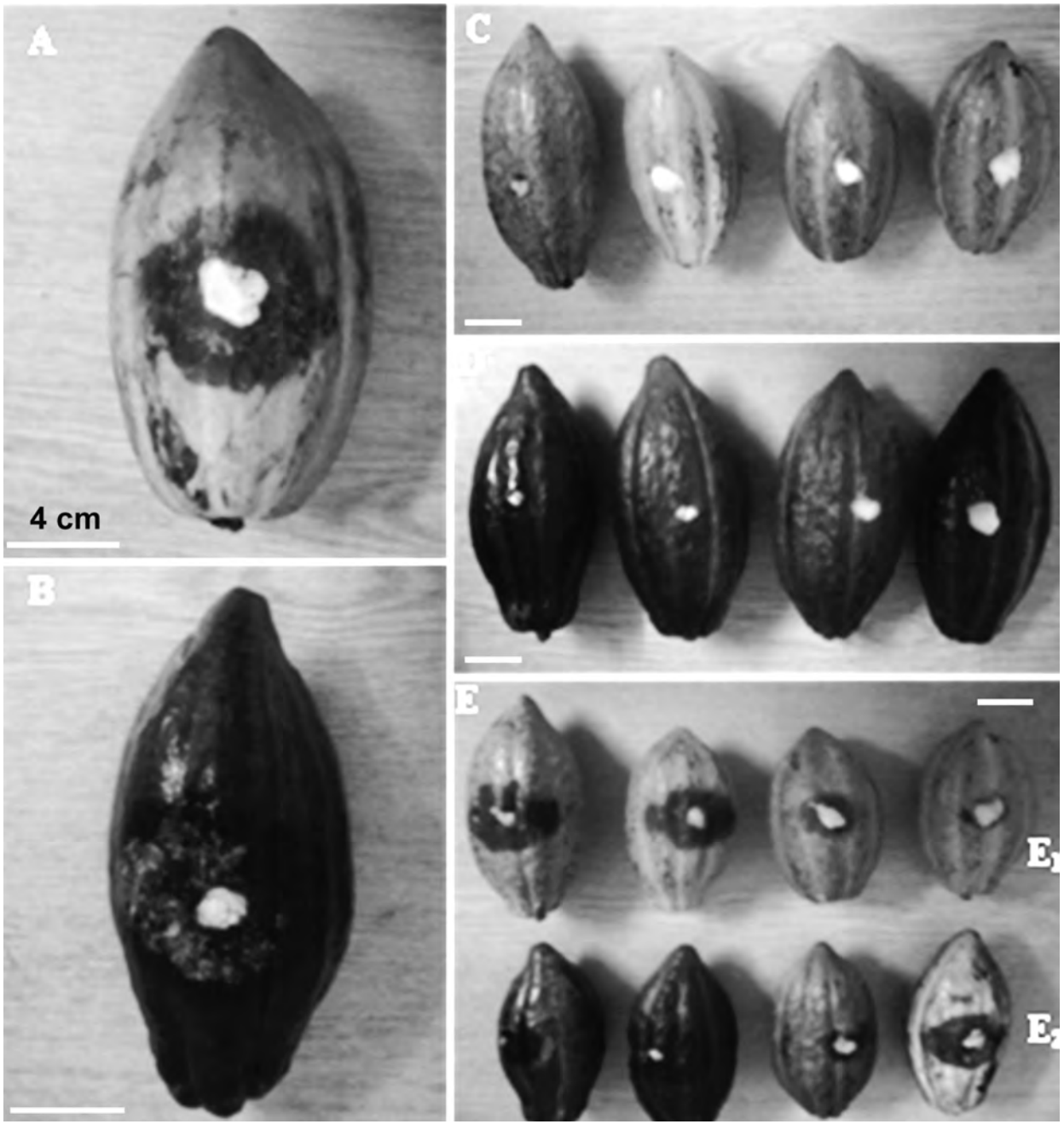

Fig. 1. Aspect of some cocoa pods, four days after treatment: inoculated parental clone T79/467 (A); inoculated parental clone SNK13 (B); scarified F79 progenies (C); scarified F13 progenies (D); inoculated progenies (E) of F79 (E_1) and F13 (E_2).

F7908, F7909, F7910, F7917, F7918, F7918, F7921, F7922, F7922, F7923, F7324, F7925, F7926, F7927 and F7928 genotypes (Table 1). In the F13 generation, the surface area of the necrosis ranged between 2.20 cm^2 and 116.34 cm^2. At the sixth dpi, the F1302, F1304, F1304, F1307, F1309, F1313, F1314, F1315, F1316, F1317, F1318, F1322, F1323, F1325 and F1329 genotypes developed very small necrotic surfaces (Table 2). In the F79 family, three days after treatment, 100% of the progeny's genotypes showed hybrid vigour. This rate decreased during the course of development of the necrosis to 70% by the fifth and sixth days. In the F13 generation, 90% of the genotypes manifested hybrid vigour on the third day. This rate dropped to 64% on the sixth day. The F1302, F1305, F1307, F1309, F1313, F1314, F1315, F1317, F1318, F1323, F1325 and F1329 genotypes showed hybrid vigour throughout the development of necrosis.

the sixth day. The F1302, F1305, F1307, F1309, F1313, F1314, F1315, F1317, F1318, F1323, F1325 and F1329 genotypes showed hybrid vigour throughout the development of necrosis.

The development of necrosis in parental and hybrid genotype pods increased with time. Enlargement of the necrotic surface was more significant in sensitive parents of SNK13 compared to the T79/467 parents ($p<0.05$).

Principal component analysis of the different genotypes with respect to surface necrosis. Principal component analysis (PCA) was used to visualize the variations in the genotypes during the development of necrosis. For the F79 family, the first two axes generated from all data represented 95.73% of the total variability of necrosis. Days 4, 5 and 6 were the dominant features in the first axis (84.34% of the total variability) while necrosis at day 3 was the highest feature in the second axis (11.39% of the total variability). Examining the two-dimensional scores in the space defined by axes 1 and 2 showed that the distribution of samples followed a pattern. The first group embodied 18 hybrids, characterized by the smallest surface necrosis from day 4; the second group, composed of parent clone SNK13 and two hybrids (F7905 and F7916) was characterized by larger surface necrosis. The third group was equally characterized by a large surface necrosis, but less than that of the second group which comprised the best parents, T79/467 and hybrids F7912, F7917 and F7930. The remaining hybrids (F7904, F7906, F7911, F7913, F7914, F7915, and F7919) were characterized by smaller surface necrosis from day 3 (Fig. 2).

For the F13 family, the first two axes explained

Table 1. Mean surface area of necrosis (cm^2) on the parental and hybrid pods of F79 progenies.

Genotypes	Mean surface area of necrosis (cm^2)			
	Day 3	Day 4	Day 5	Day 6
F7901	0±0a	3.8±0.4ab	17.7±1.8d	31.5±1.5e
F7902	0±0a	2.7±0.3ab	5.5±0.3abc	9.9±1.8a
F7903	0±0a	7.6±1.3cd	15.8±1.2d	21.4±3.6bcd
F7904	0±0a	21.6±2.5gh	39.7±1.2g	59.0±3.4hi
F7905	6.1±0.8d	18.7±2.4g	59.4±1.1j	84.5±2.8k
F7906	3.2±0.9b	12.7±0.7e	31.3±0. 9f	56.5±1.8hi
F7907	0±0a	0±0a	2.2±1.0a	15.6±3.1abc
F7908	0±0a	3.8±0.6ab	16.2±1.0d	21.6±4bcd
F7909	0±0a	0.8±0.2a	1.6±0.6a	16.2±3.5abc
F7910	0±0a	0.7±0.2a	2±0.6a	15.7±1.5abc
F7911	3.0±0.4b	15.8±1.6[f]	31.0±1.2f	57.5±4.7hi
F7912	2.7±0.2b	7.6±0.6cd	17. 7±0.9d	47. 4±1.8g
F7913	5.6±1.7d	12.3±0.9e	40.6±5.1g	54.2±4.8ghi
F7914	5.1±1.1c	19.6±0.8g	48.2±6.3h	60±5.8i
F7915	0±0a	20.7±3.9gh	55.4±1.3i	74.9±6.1j
F7916	8.1±1.3e	21.5±1.6gh	36.8±1.4g	85.8±5.1k
F7917	5.7±1d	9.0±1.5d	24.2±1.6e	32.1±3.1e
F7918	0±0a	2.3±0.4ab	16.1±1.0d	22.4±4.5cd
F7919	2.6±0.6b	23.3±2.9h	37.5±2.1g	50.5±3.2gh
F7920	0±0a	3.2±0.3ab	17. 6±1.2d	28.3±1.9de
F7921	0±0a	0±0a	3.7±0.7a	12. 6±1.1abc
F7922	0±0a	2.9±0.3ab	8.3±1.8bc	13.6±1abc
F7923	0±0a	2.2±0.3ab	8±0.1bc	11.2±2.4a
F7924	0±0a	2.4±0.4ab	7.8±1.2bc	13.3±2.9abc
F7925	0±0a	5.3±1bc	8.7±1.6c	14.9±3.8abc
F7926	0±0a	3.7±0.7ab	9.2±1.3c	13.7±2.7abc
F7927	0±0a	0±0a	4.0±0.5ab	8.8±1.8a
F7928	0±0a	0±0a	3±0.8a	11.98±3.1ab
F7929	0±0a	10.5±0.5de	18.9±2.3d	38.8±9.0f
F7930	2.7±0.1b	9.6±1.2de	29.6±1.86f	40.4±2.1f
SNK13	12.4±1.9f	26.8±2.8i	36.5±2.8g	59.0±3.4hi
T79/467	4.1±0.5bc	12.3±1.6e	22.7±0. 9e	39.6±2.2f

Values followed by the same letter within column are not significantly different (P> 0.05).

Table 2. Mean surface area of necrosis (cm^2) on the parental and hybrid pods of F13 progenies.

Genotypes	Mean surface area of necrosis (cm^2)			
	Day 3	Day 4	Day 5	Day 6
F1301	0±0a	10.8±2.1efg	34.3±0.9i	45.5±4.2h
F1302	0±0a	0±0a	3.3±0.6ab	10.1±0.6abc
F1303	0±0a	4.7±0.9bcd	32.8±2;3i	43.7±1.9h
F1304	0±0a	0±0a	5.78±1.4ab	27.5±3.9fg
F1305	0±0a	0±0a	2.4±0.7a	8.4±0.8ab
F1306	14±2.4h	17.12±1.7ij	33.3±3.2i	53.7±2.5i
F1307	0±0a	2.24±0.6abc	4.4±0.6ab	6,2±1.5ab
F1308	7.3±1.4e	13.7±1.4gh	26.1±3.3gh	42.1±4.6h
F1309	0±0a	4.94±1.9cd	10. 27±0.6bcd	24.3±2.9ef
F1310	14.7±1.1h	25.9±0.7mn	54.2±5.2kl	116.4±4.8n
F1311	0±0a	9.5±1.8ef	19.8±2.8ef	31.8±3.6g
F1312	14.1±0.8h	21.2±3.4kl	57.9±4.1l	74.9±1.8l
F1313	1.5±0. 3ab	3.1±0.5abc	13.5±0.9cd	20.9±1.3ef
F1314	1.8±0.6ab	7.1±1.3de	7.3±1.1abc	17.8±0.4de
F1315	0±0a	10.7±1.7efg	12.6±1.5cd	16.6±1.4cde
F1316	2±0.4ab	7. 4±0.6de	13.1±1.5cd	26.2±3.6fg
F1317	0±0a	4. 6±0.9bcd	6.2±0.8ab	11.2±0.9bcd
F1318	0±0a	0.7±0.1a	2.7±0. 4a	16.9±1.1cde
F1319	5.8±1.3d	30.9±3. 5n	44.8±6.1j	55.3±4.5i
F1320	2. 4±0.1bc	12.1±1.6fgh	36.3±4.9i	53.7±0.7i
F1321	7. 9±0.3e	23.7±2.2lm	50.3±7.2k	102.1±3.6m
F1322	0±0a	12.1±1.7fgh	15.6±1.4de	28.2±1.9fg
F1323	0±0a	3.3±0.5abc	7.4±1.2abc	18.1±1.1de
F1324	9.7±0.5f	19.8±1.3jk	43.1±2.6j	69.4±2.9k
F1325	0±0a	0.9±0.2ab	4.6±0.7ab	12.1±2.8bcd
F1326	3.2±0.8bc	8.8±2.2ef	32.6±1.5i	64.1±2.2jk
F1327	4±0.7c	15.3±0.9hi	30.4±1. 1hi	64.2±5
F1328	2.8±0.3bc	19.7±1.6jk	43.9±2.3j	53.5±9.1i
F1329	0±0a	0±0a	1.6±0.4a	3.7±0.5a
F1330	3.3±0.4bc	27.4±2.8mn	59.2±4.6l	78.6±3.2l
SNK13	12.4±1.9g	26. 8±2.8mn	36.5±2.8i	59.1±3.4i
T79/467	4.1±0.5c	12.3±1.6fgh	22.7±0. 9fg	39.6±2.2g

Values followed by the same letter within column are not significantly different (P> 0.05).

94.48% of the total variability. Necrosis on days 4, 5 and 6 were the dominating features in the first axis (86% of the total variability) while day 3 was the highest feature in the second axis (8.48% of the total variability). Examining the two-dimensional scores in the space defined by axes 1 and 2 showed that the distribution of samples followed a pattern of five groups. The first group embodied parental genotype SNK13 and hybrids F1306, F1310, F1312, F1321 and F1324, characterized by larger surface necrosis from day 3, the second group consisted of parent clone T79/467 and hybrid F08 which presented the same pattern, while the third group of six hybrids (F1319, F1320, F1326, F1327, F1328 and F1330) was characterized by larger surface necrosis from day 4. The fourth group characterized by a smaller surface necrosis from day 3 was composed of hybrids F1301, F1303, F1309, F1311, F1315 and F1322. The remaining hybrids (F1304, F1305, F1313, F1314, F1316, F1318, F1323 and F1325) were characterized by smaller surface necrosis from days 3 and 4 (Fig. 3).

Productivity assessment. The productivity of parental and hybrid genotypes was assessed by measuring the weight of 100 cocoa beans over a period of three years. The sensitive parental clone, SNK13 (406.17 g) was more productive than the tolerant clone, T79/467 (360.50 g). In the F79 family, the highest productivities were observed in the F7921, F7915, F7917, F7919, F7909 and F7929 genotypes with a maximum of 556.70 g in F7921 (Fig. 4, A). Within the F13 family, the most productive genotypes were F1304, F1324 and F1314 with respective values of 507.05, 519.01 and 581.23 g (Fig. 4).

In the two families F79 and F13, there was a remark-

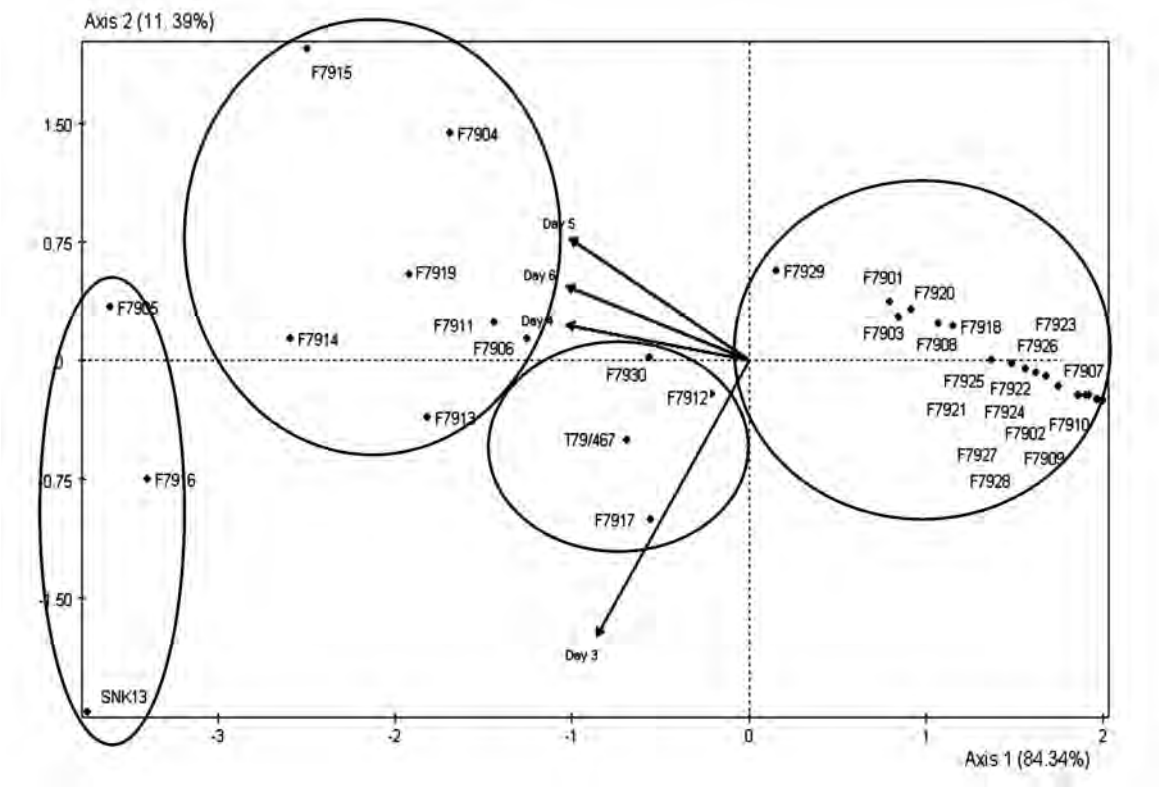

Fig. 2. Principal component analysis based on the necrotic surface area of cocoa pods between day 3 and day 6 of hybrid genotypes from the F79 generation.

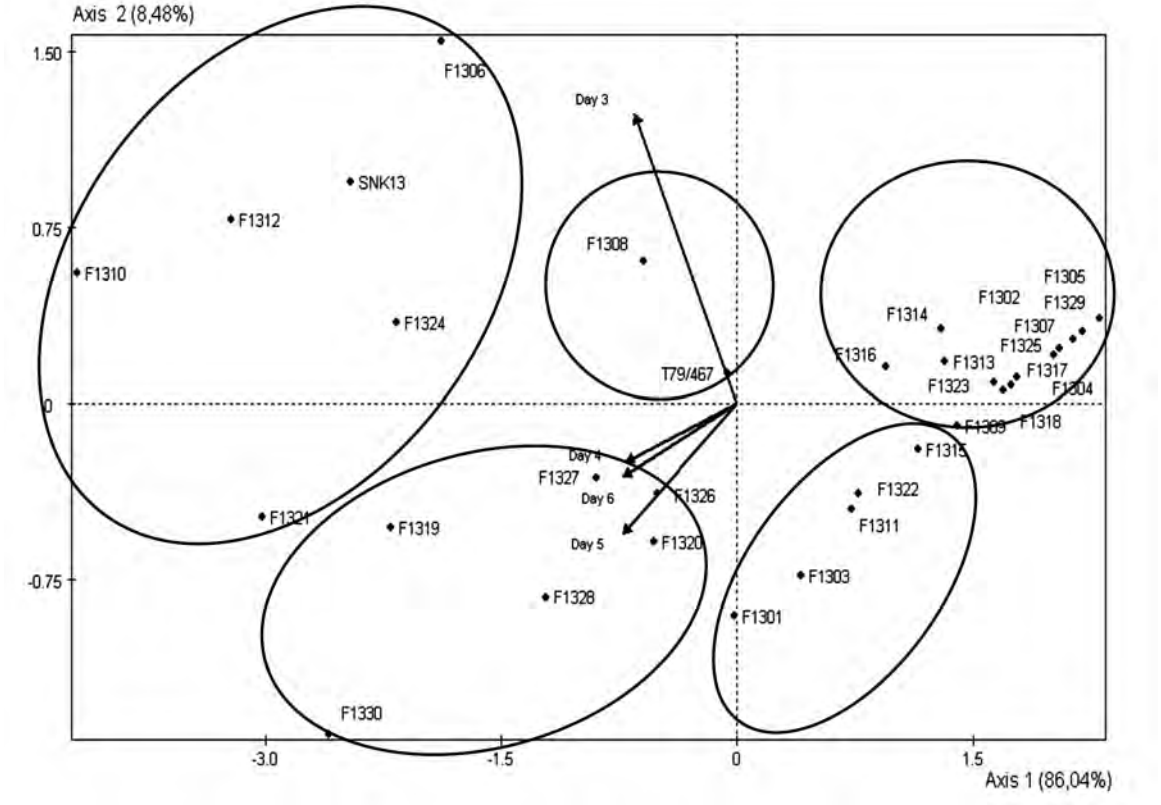

Fig. 3. Principal component analysis based on the necrotic surface area of cocoa pods between day 3 and day 6 of hybrid genotypes from the F13 generation.

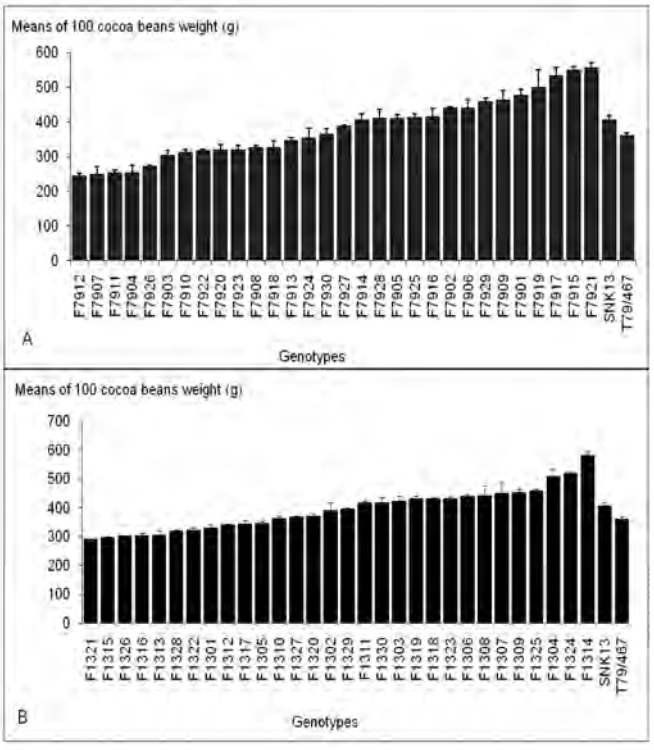

Fig. 4. Assessment of parent and hybrid productivities in the F79 (A) and F13 (B).

able manifestation of hybrid vigour considering the productivity character. In fact, the F7921, F7915, F7917, F7919, F7909, F7929, F1304, F1324, F1314, F1309, F1325 and F1309 genotypes showed higher yields than those of the best parent SNK13. Results obtained for productive character also revealed the existence within the progenies of more productive genotypes than those of the best parent SNK13. Furthermore, it is currently accepted that crosses between Forastero (T79/467) and a Trinitario (SNK13) give hybrids that generally show a good precocity and high yields, associated with a much better tolerance to diseases.

Hierarchical classification of the different genotypes with respect to productivity. Hierarchical classification obtained from productivity values enabled 4 groups to be distinguished for each family at 95% homogeneity. In the F79 family, the four genotypes of group 3 with the average productivity values of 535.14 g were significantly more than those of the best parent, SNK13 (406.17 g). In contrast, the genotypes of groups 1 and 2 showed 253.98 and 331.76 g as respective mean productivity values; these values are less than those of the tolerant parent, T79/476 (360.50 g) (Fig. 5). A similar distribution was observed in the F13 family (Fig. 6). The group 1 genotypes (F1304, F1324 and F1314) were more productive (507.05, 519.09 and 581.23 g, respectively) than the best parent, SNK13. Group 3 and 4 genotypes with respective mean productivity values of 305.86 and 364.61 g revealed a similar behavior to that of the less productive parent, T79/467. Group 3 genotypes of the F79 family as well as groups 1 and 2 of the F13 generations showed an aptitude for parental genotypic combinations. The hierarchical classification of the genotypes from F79 and F13 progenies for the productive characters illustrated that about 45% of the genotypes manifested hybrid vigour for the characters.

Heritability assessment of productivity and necrosis development characters. Heritability (h^2) that represents the overall biochemical and molecular effects of nucleic acids in the transmission of the necrosis and productivity developmental characters was estimated for each progeny. This estimation was provided by the slope of the regression straight line graph between the mean values of the parental and progeny genotypic performances (Fig. 7). Concerning the necrosis development, the heritability value obtained in the F79 family (F79: ♀T79/467×♂SNK13) was similar to that of F13 (F13: ♀SNK13×♂T79/467). These values were respectively 0.91 and 0.81. On the other hand, the heritability of the productivity character was relatively lower (0.52 for the F13 and 0.67 for F79).

DISCUSSION

Development of the necrotic surfaces evolved regularly in all inoculated genotypes until the sixth dpi. Fifteen genotypes in the F13 generation and 70% of the F70 family developed very small necrotic surfaces on the sixth dpi. The development of necrosis for the parental and hybrid genotype pods increased with time. These results are in agreement with those obtained by Nyassé (1997) on *T. cacao* leaf disks in the laboratory, Djocgoue *et al.* (2006) on leaves attached to the plant, and by Djocgoue (1998) on the pods of the same plant in the laboratory. The evolution of necrotic surfaces was more significant in the sensitive parents SNK13 compared to the T79/467 parent ($p<0.05$). These results conform with those documented by Nyassé *et al.* (2002) on cocoa leaf disks and by Omokolo *et al.* (2002) on cocoa pods. The existence within the same generation of genotypes that develop a necrotic surface area smaller than that of the intermediate parent, suggests a suitable capacity to parental genotypic combinations. Similar results were reported by Nyassé *et al.* (2002) on the assessment of field infection incidence. The effects of global aptitudes to parental genotypic combinations was substantial for the rot rate of cocoa pods (Cilas *et al.,* 2004), suggesting a primary and additive transmission of resistant characters (Tan and Tan, 1990).

PCA based on the surface area of necrosis distinguished 5 and 4 groups in the F13 and F79 generations, respectively. PCA of genotypes of the two reciprocal

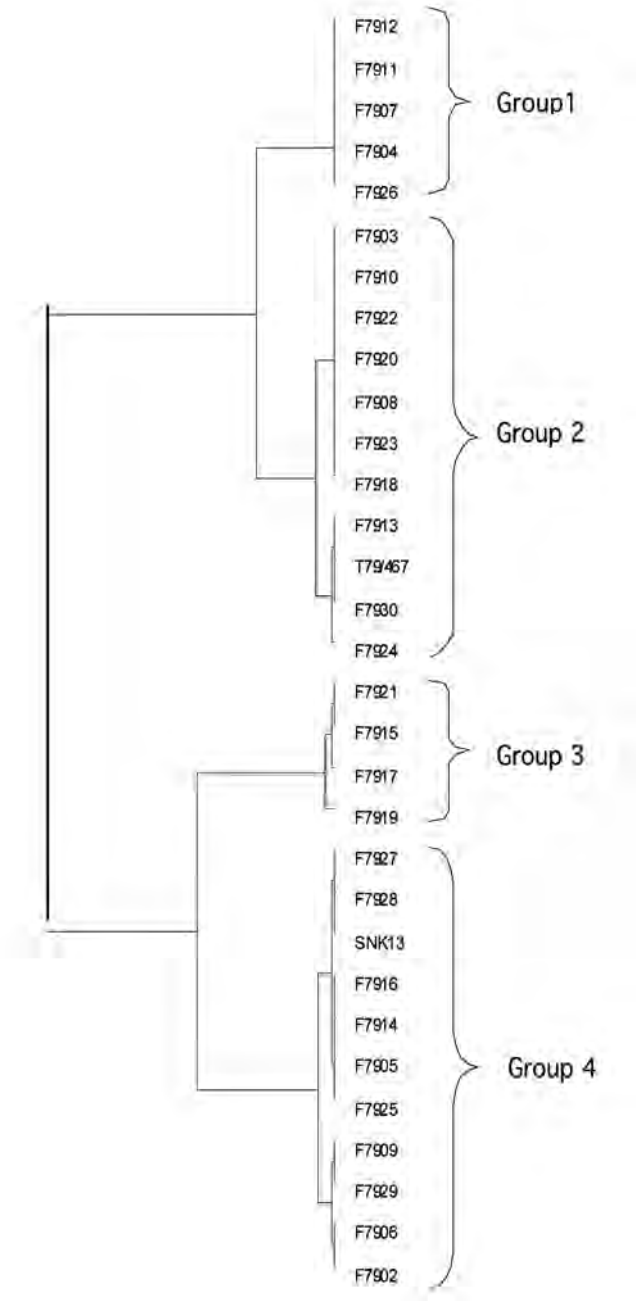

Fig. 5. Direct hierarchical classification of hybrid genotypes from the F79 generation with respect to seed weight.

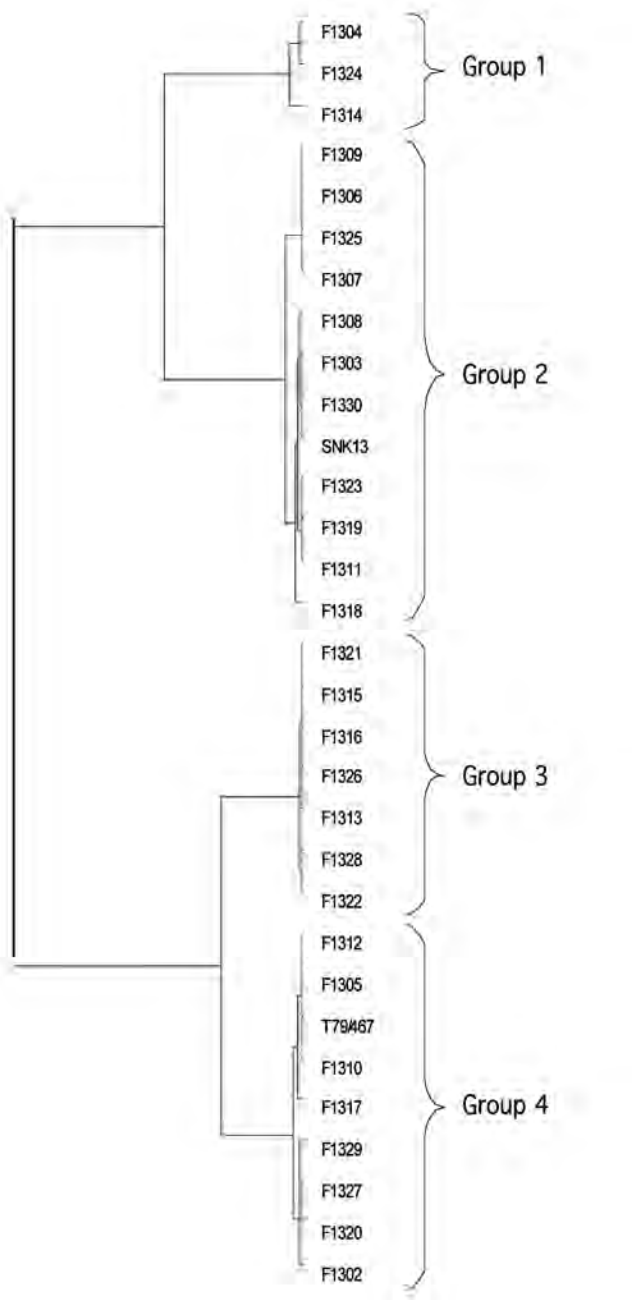

Fig. 6. Direct hierarchical classification of hybrid genotypes from the F13 generation based on seed weight.

families revealed that during the development of the necrosis, 60% of the hybrids from the F13 and F79 families were characterized by a lower surface necrosis compared to the best parent. Thus, these hybrids manifest hybrid vigour for the necrotic development characters. This result confirms a good aptitude to parental gene combinations (Cilas *et al.*, 2004; Djocgoue *et al.*, 2006).

The productivity of parental clone SNK13 was more important than that of the tolerant clone T79/467 (360.50 g). In the two families F79 and F13, there was a remarkable manifestation of hybrid vigour for the productivity character. Furthermore, it is currently admitted that the crossing between Forastero (T79/467) and a Trinitario (SNK13) gives hybrids that generally show a good precocity and high yields, associated with a much better tolerance to diseases, although a certain heterogeneity is partially associated with the level of heterozygosis in the parents (Mossu, 1984). In addition, Sounigo *et al.* (1993) showed a high hybrid productivity resulting from the crossing between Upper Amazonian Foratero and a Trinitaro. Hierarchical classification of the different genotypes with respect to productivity enabled 4 groups to be distinguished for each family at 95% homogeneity. This classification illustrates that about 45%

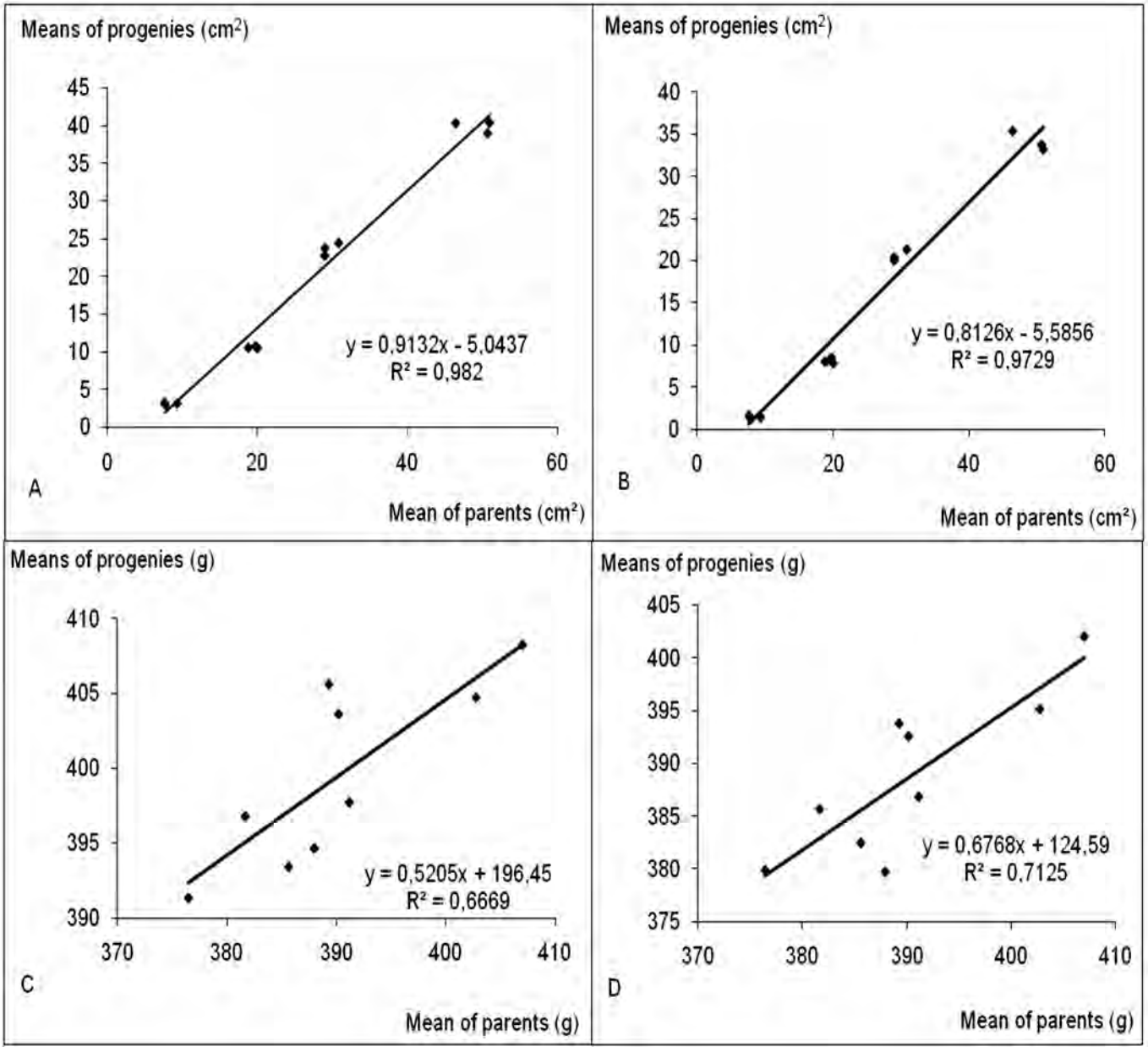

Fig. 7. Evaluation of heritability (h^2) using the regression slope between parental clones and their progenies for necrotic size [Families F13 (A) and F79 (B)] and productivity of cocoa beans [Families F13 (C) and F79 (D)].

of the genotypes manifest hybrid vigour for this trait. This reveals the existence within the progenies of more efficient genotypes than the best parent and that these can be used as parents in future improvement programs (Lockwood *et al.*, 2007).

Heritability assessment of necrosis development characters are 0.91 and 0.81 and productivity characters are 0.52 and 0.67 (for F13 and F79 respectively). These results contrast with those by Sounigo *et al.* (1993) and Soria *et al.* (1974), but match with Pardo and Enriqutz (1987) and Cilas *et al.* (1989) reports that showed the existence of a positive correlation between the productivity of the clones and their global combining ability. These results are also contradictory to those by Lockwood *et al.* (2007) who showed a low heritability of the traits production and necrosis development in cocoa plants. These differences, however, can find an explanation in the fact that productivity measurements were not carried out at the same age. In addition, in the experimental conditions of the present investigation, the parental and hybrid genotypes were planted in the same plot, and this had the effect of minimizing environment-related effects, rendering the heritability estimations more trustworthy (Cilas, 1991).

Regardless of the studied character, the absence of a significant difference between the heritability values from reciprocal crossing portrays the absence of maternal heritability. This observation suggests that the heri-

tability of productivity and the development of necrosis is nuclear rather than cytoplasmic. This is in agreement with the investigations of Nyassé *et al.* (1995) after infection of disks of cocoa leaves with UPA134xSNK64 and SNK64x UPA164 by zoospores of *P. megakarya.* The works of Djocgoue *et al.* (2006, 2007) on leaves attached on the plant are also in agreement.

The objective of the present investigation was to search, in the framework of comparative hybrid tests of genotypes, for the most effective characters among those analyzed and to identify the parental genotypes that show good combining potentials. The main results obtained showed that F7902, F7909, F7917, F7921, F7922, F7925, F7928, F1304, F1307, F1309, F1314, F1318, F1323 and F1325 developed very small necrotic surface areas and had high yields. These genotypes qualify themselves as the best ones since being the most tolerant and productive. A mass multiplication of these genotypes and a bulk distribution to farmers is likley to boost cocoa farming in Cameroon. Furthermore, the parental genotypes, SNK13 and T79/467, show good aptitudes for the combination of the two studied characters, and their introduction into the biclonal planting field will be beneficial.

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