Available online at www.ijpab.com

DOI: http://dx.doi.org/10.18782/2320-7051.7305

ISSN: 2320 – 7051

Int. J. Pure App. Biosci. **7 (2):** 1-9 (2019)

Research Article

International Journal of Pure & Applied Bioscience

Agro-Morphological Evaluation of Three Exotic Maize Genotypes (*Zea mays* L.) in the Sahelian Context: Prospects for Improving Local Production

Oumarou Abdoulaye Moussa[1*], Issoufou Hassane Bil-Assanou[1], Ali Mahamane[3], Saadou Mamane[1] and Mainassara Zaman-Allah[1]

[1]Département de Biologie, Faculté des Sciences et Techniques, Université Dan Dicko Dankoulodo de Maradi, Niger

[2]Département des Sciences et Techniques de Productions Végétales, Faculté d'Agronomie et des Sciences de l'Environnement, Université Dan Dicko Dankoulodo de Maradi, Niger

[3]Département de Biologie, Faculté des Sciences, Université de Diffa, Niger

*Corresponding Author E-mail: oa_moussa@yahoo.fr

Received: 18.02.2019 | Revised: 22.03.2019 | Accepted: 29.03.2019

ABSTRACT

Agro-morphological characterization of genotypes under extreme environmental conditions is important for understanding functional diversity and productive potential of crops. In this study, four maize genotypes (Zea mays L.) were evaluated in the Sahelian context under two water regimes: stressed and optimal using a split-plot design with four repetitions and two factors (genotype, water regime). Our results showed significant differences between the genotypes for several agro-morphological traits. The principal component analysis of the thirteen traits that were measured revealed that the first two components explain 95.25% and 95.95% of the total variation for optimal and water stress conditions respectively. In addition, our results showed that eight of the thirteen studied traits contribute the most to discriminating the four genotypes under both growth conditions.

Keys words: *Maize, Hybrid, Productivity, Drought, Sahel*

INTRODUCTION

Maize (*Zea mays* L.) is ranked third after wheat and rice in world production FAO[15]. It is a staple food for many people in tropical and subtropical Africa[34]. In Niger, its importance has increased as it has progresively replaced other staple foods such as sorghum and millet in urban centers[43]. Maize can be grown both in the rainy season and in the dry season under irrigation, and its cultivation would therefore make up for the inadequacies of the rainfed system. However, production is very low and can not meet the food demand of consumers in Niger. This situation results from the combination of the effect of pedo-climatic constraints and the limited use of improved seeds.

Cite this article: Moussa, O.A., Bil-Assanou, I.H., Mahamane, A., Mamane, S. and Zaman-Allah, M., Agro-Morphological Evaluation of Three Exotic Maize Genotypes (*Zea mays* L.) in the Sahelian Context: Prospects for Improving Local Production, *Int. J. Pure App. Biosci.* **7(2):** 1-9 (2019). doi: http://dx.doi.org/10.18782/2320-7051.7305

Harnessing the genetic diversity of maize is particularly important for maintaining and improving the productivity of this species in developing countries[22] such as Niger. Therefore, the inventory and agro-morphological characterization of these genetic resources (exotic and localy adapted germplasm) would represent an important database for the maize improvement program in Niger. Morphological characterization is one of the important steps in the description and classification of germplasm of cultivated plants[27,48,36]. Indeed, any improvement program is necessarily based on morpho-phenological variability[42].

Several improved drought-tolerant maize genotypes that are already popular have good yields in farmers fields and are popular with consumers in Kenya, Malawi, Zambia and Zimbabwe (CIMMYT). In order to understand the local adaptation of these varieties, an agro-morphological variability assessment program was establised in South-East Niger.

The objective of this study is to analyze the agro-morphological variability of the four maize genotypes in optimal and water stress conditions and to determine the water stress tolerance traits that can be used for varietal improvement by local breeding programs.

MATERIAL AND METHODS

2.1 Biological material and growth conditions

The study was conducted using four maize hybrids of which three (CZH131001, CZH142013, SC303) were obtained from the International Maize and Wheat Center (CIMMYT-Zimbabwe) and the fourth (P3Kollo) was from the National Institute for Agronomic Research of Niger (INRAN) (Table 1). P3Kollo is widely grown in Niger.

The trial was carried out during the hot dry season (March to June) in 2016 and 2017 at the Keguel site in Jiratawa (13 ° 41 'N, 7 ° 14' S). This site is located 10 km from the city of Maradi (Niger) characterized by average monthly minimum and maximum temperatures of 27 ° C and 45 ° C respectively. The soil used is sandy-loamy with a granulometry of 85.17% (w / w) sand, 13.44% (w / w) silt and 1, 39% (w / w) of clay. The water pH and $pHCaCl_2$ of the soil solution were 7.20 and 6.97, respectively.

2.2 Experimental design and trial management

The experimental design was a Split-Plot with 4 repetitions and 2 factors: water regime and genotype. Each repetition had 16 rows that were 4m long with an inter-row spacing of 80cm and 1m between repetitions. Each plot had 4 rows. Irrigation was conducted every 5 days for the control plots and every 10 days for plots under water stress. Water stress was imposed before flowering and until the end of the cycle. The spatial arrangement of the plots was the same in 2016 and 2017. The four genotypes were hand planted at the rate of two seeds per planting station on March 1st in 2016 and 2017. Prior to sowing, the seeds were treated with a fungicide to prevent germination being affected by soil born fungi. NPK was applied at planting at a rate of 100 kg / ha and urea (46%) two weeks later at the rate of 120 Kg /ha. The plots were hand weeded 15 days and 30 days after emergence.

2.3 Data collection and statistical analysis

Thirteen agro-morphological characters were measured from the four central rows of each plot. The 2 border rows were discarded in order to avoid border effect. The list of characters included are listed in Table 2. A two-way analysis of variance was performed to test the effect of "genotype", "irrigation regime" and their interaction on agro-morphological traits according to the Fisher test ($p< 0.05$) (GENSTAT 16th Edition). A principal component analysis was performed between the agro morphological traits measured using the XLSTAT 2018 software. Two axes were retained for the analysis of the results in both water regimes based on the Kaiser-Meyer-Olkin (KMO) criterion.

RESULTS

3.1 Assessment of variation in agro-morphological traits

Table 3 shows the effect of genotype and irrigation regime, as well as their interaction on agro-morphological traits. All the traits studied presented significant variation except ASI, NE, SD, 100-gw, MF, FF, PH, EH and EL for the interaction genotype * irrigation regime.

The mean, minimum, maximum and standard deviation values for all studied traits are presented in table 4. Large differences are observed between the minima and maxima for important agronomic traits such as female flowering (FF), plant height (PH), ear height (EH), number of ears (NE) and yield (GY). The window between sowing and FF was delayed by 4 days due to drought stress (66 ± 1.78 days for optimal and 70 ± 1.4 days for drought stress conditions). Plant height (PH) ranged from 97.77 to 143.33 cm with an average of 128.57 ± 20.78 and from 97.77 to 122.66 cm with an average of 112.6 ± 10.53 under optimal and drought stress conditions, respectively (Table 4).

3.2 Principal component analysis

The output of the principal component analysis showed that plant height, stem diameter, internode length, ear length, ear diameter, ear number, male flowering, female flowering and the 100 grain weight contribute most to the first axis under optimal conditions (Table 5). This axis can therefore be described as the axis of precocity and growth. Besides, anthesis silking interval, ear weight and grain yield contribute to the second axis which can be defined as that of yield performance.

Under drought stress, male and female flowering, plant height, ear height, inter-nod lenght, the lengh and diameter of ears and 100-grain weight contribute the most to the first axis (Table 5). This axis can therefore be described as the axis of growth and precocity. On the other hand, stem diameter, number of ears and their weight, anthesis and silking interval and grain yield are the most contributors to the second axis, which can be referred as the axis of yield performance.

3.4 Traits and genotypes associations

Different trends of trait associations and trait profiles were observed under different growing environment as depicted by the GGE biplot in this study (Fig 1). In the biplot, the cosine of the angle between two traits approximates the correlation between the traits; and hence associations among traits could easily be visualized from the biplot. There is a positive association between two traits if the angle is less than 90°, a negative association if the angle is greater than 90 ° and no association if the angle is exactly 90°[47]. Under optimal conditions, grain yield had positive association with ear related traits (EW, NE, ED and 100-gw), with relatively stronger relationship with ear weight (EW) and number of ears (NE) (Fig1a). In addition, there was a slighly negative association between yield and flowering (MF and FF) and quite strong negative association with ASI. Regarding trait-genotype association, CZH131001 and CZH142013 presented a strong association with grain yield components traits (Figure 1a). Under drought stress conditions, the traits associated to grain yield are, in general, similar to those observed under optimal conditions; except for ear diameter (Figure 1b). In addition, male flowering and ear height seem to be associated with grain yield but the association was quite weak. On the other hand, similar to optimum conditions, ASI had negative association with grain yield but stronger under drought stress conditions (Figure 1a).

DISCUSSION

The response to the irrigation regime was significant for all the traits that were evaluated. In drought stress conditions, our results showed an increase in the anthesis silking interval. These results are similar to those of Sanou[39], who reported a larger interval between male and female flowering in S2 lines of FBC6 under water deficit conditions. A larger gap between male and female flowering causes asynchronous flowering; leading to incomplete pollination and seed set. This represents a major contributor to yield losses in the maize crop. An increase of one day of ASI can cause a yield reduction of 10% compared to the optimal conditions[44]. In most cases, it was observed that the larger the ASI, the lower the yield[4]. Regarding the other agro-morphological traits, there was a significant inter-genotypic variability. These results are in agreement with those of the study conducted by N'da *et al*.[29] on the morphological diversity of local maize varieties collected in central and west-central Ivory Coast. The phenotypic variations observed for the two irrigation regimes are largely the result of genotype by environment interaction. Indeed, several studies have shown for example that weather variables (day length, temperature, relative humidity etc…) have substantial effects on plant vegetative and physiological development[19,25,6,26,7,9]. There was a significant variability in grain yield and ear weight, similar to previous reports by N'da *et al*.[30] and Deffan *et al*.[10] and A.A. Razak *et al*. in Niger. Traits associations are an indispensable tool for breeders in selecting the traits to be included in the breeding process. Indeed, associations between traits can facilitate genetic improvement since when traits are positively associated, the improvement of one will lead to that of others[2]. This study has shown that several ear related traits that are easier to mesure compared to grain yield as strongly associated to the later. The anthesis silking interval was negatively correlated with yield performance of the genotypes, especially under drought conditions as reported by Bolanos J. *et al*.[5] who found that grain yield is strongly dependent on the difference between male and female flowering dates. The positive correlation observed between yield and its components (NEP, PER and P100G) in both environments is a good indicator for the indirect selection of high yielding genotypes using the yield components that are easier to mesure. The two identified drought tolerant hybrids have the potential to enable maize production improvment in Niger if they prove to be adpated to the local agro-ecological conditions through multi-location trials.

Table 1: Characteristics of the different maize genotypes used during study

Genotype	Origin	Grain color
CZH131001	CIMMYT/ZIMBABWE	White
CZH142013	CIMMYT/ZIMBABWE	White
SC303	CIMMYT/ZIMBABWE	White
P3KOLLO	INRAN/NIGER	Yellow

Table 2: List of agro-morphological traits measured on maize plants during the study

Traits	Abreviation	unit
Ear number	EN	_
Ear height	EH	cm
100 –grain weight	100-gw	g
Grain yield	GY	kg/ha
Stem diameter	SD	cm
Plant height	PH	cm
Ear weight	EW	g
Male flowering	MF	days
Female flowering	FF	days
Anthesis silking interval	ASI	days
Internode lengh	INL	cm
Ear lengh	EL	cm
Ear diameter	ED	cm

Table 3: Variation of agro-morphological traits in relation to genotype, irrigation regime and their interaction effect in Jirataoua (Maradi, Niger)

Effet	EN	100-gw	GY	SD	EW	EL	ED	MF	FF	ASI	INL	EH	PH
GEN	0.001	<.001	<.001	<.001	<.001	<.001	0.014	<.001	<.001	0.018	<.001	<.001	<.001
IR	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
GEN*IR	0.11	0.21	0.014	0.74	<.001	0.98	0.002	0.24	0.11	0.24	0.011	0.08	0.87

IR : irrigation regime ; GEN : genotype ; IR*GEN : interaction irrigation regime-genotype ; ns : non significant at $p = 0,05$.

Table 4: Descriptive statistics of the thirteen agromorphological traits studied under optimum and drought stress conditions

Optimum conditions					Drought stress conditions				
Variables	**Mean**	**Min**	**Max**	**SD**	**Variables**	**Mean**	**Min**	**Max**	**SD**
MF	61	60	62	1,37	**MF**	63	61	64	1,51
FF	64	62	66	1,78	**FF**	68	65	70	1,4
ASI	3	2	4	0,66	**ASI**	5	4	6	0,14
PH	128,57	97,77	143,33	20,78	**PH**	112,6	97,77	122,66	10,53
EH	53,03	35,29	67,27	13,28	**EH**	45,62	35,29	53,16	8,02
SD	1,59	1,23	1,82	0,26	**SD**	1,27	1,2	1,42	0,1
INL	8,68	6,09	10,03	1,76	**INL**	6,33	4,55	7,69	1,3
EL	11,62	11,07	11,99	0,44	**EL**	10,06	9,49	11,07	0,7
ED	3,7	2,51	4,89	0,98	**ED**	2,71	2,51	2,97	0,2
NE	27	24	34	4,48	**NE**	14	11	17	2,77
EW	1079,65	669,39	1870,74	540,25	**EW**	477,82	193,48	785,75	287,96
100-gw	21,16	18,22	23,61	2,23	**100-gw**	18,2	16,39	19,33	1,3
GY	791,48	510,3	1099,89	281	**GY**	397,55	139,31	671,17	241,97

Table 5: Contributions of individual traits to the first two multivariate axes of the principal components analysis

	Optimum conditions			Drought stress conditions	
	Axes			**Axes**	
	1	**2**		**1**	**2**
MF	**0,71**	0,26		**0,84**	0,13
FF	**0,89**	0,09	**MF**	**0,93**	0,04
ASI	0,16	**0,79**	**FF**	0,18	**0,8**
PH	**0,86**	0,05	**ASI**	**0,99**	0,01
EH	**0,67**	0,27	**PH**	**0,8**	0,01
SD	**0,92**	0,08	**EH**	0,24	**0,72**
INL	**0,92**	0,02	**SD**	**0,97**	0,03
EL	**0,92**	0,02	**INL**	**0,87**	0,1
ED	**0,81**	0,19	**EL**	**0,75**	0,23
NE	**0,47**	0,45	**ED**	0,3	**0,67**
EW	0,26	**0,65**	**NE**	0,05	**0,92**
100-gw	**0,86**	0,13	**EW**	**0,63**	0,34
GY	0,22	**0,73**	**100-gw**	0,01	**0,92**

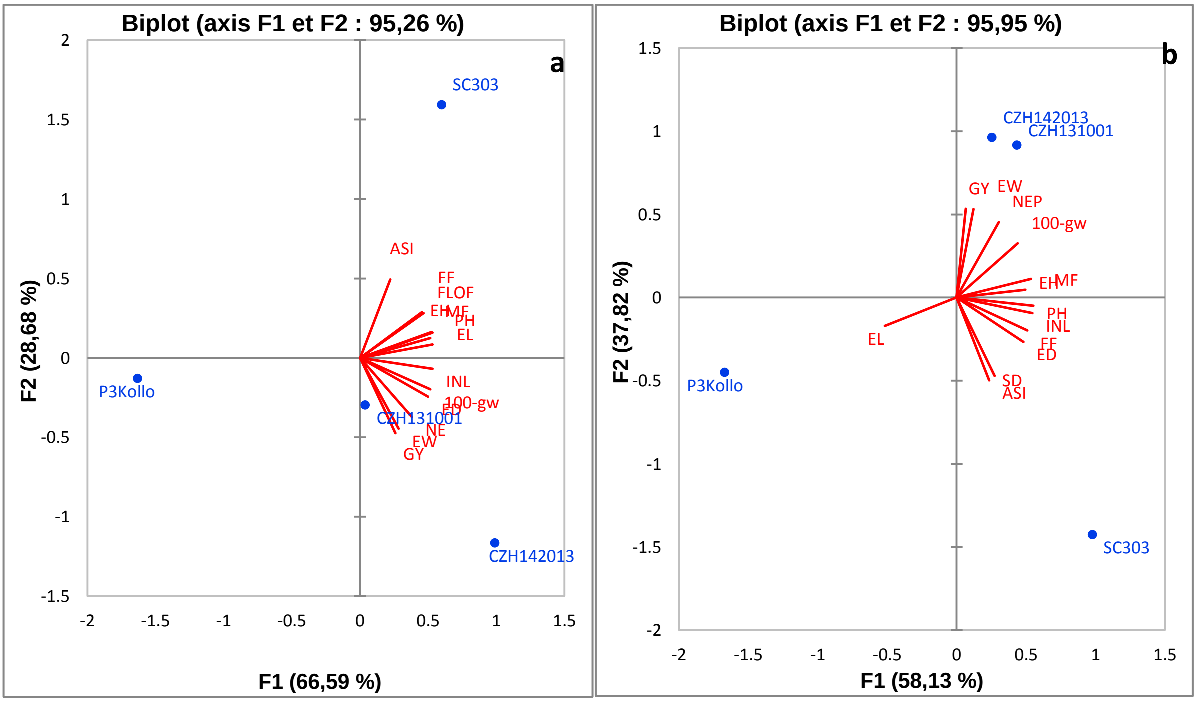

Fig. 1: Genotype by trait biplot under (a) optimal and (b) drought stress conditions

CONCLUSION

The selection of maize for drought resistance is a complex task, particularly because drought can affect the crop at any stage of development. Our study has shown that genotypes of maize grown under optimal and drought conditions differ for important agro-morphological traits. Due to their association with grain yield, a number of traits, including 100-gw, EN, EW and ASI represent useful secondary traits for the selection of high-yielding genotypes in drought prone areas. The two tolerant genotypes (CZH131001 and CZH142013) identified for the two irrigation regimes (optimal and managed drought) can be tested for adaptation to local conditions through multi-location on-farm trials and promoted to farmers in an attempt to improve maize production in the country.

REFERENCES

1. Moussa, A. A., Salako, V. K., Charlemagne Gbemavo1, D. S. J., Zaman-Allah, M., Kakaï, R. G., et Bakasso, Y., Performances Agro-Morphologiques Des Variétés Locales Et Améliorées de Maïs Au Sud-Ouest Du Niger. *Africa Crop Science Journal*, **26(2):** pp. 157 173A (2018).
2. Bakasso, Y., Ressources génétiques des roselles (*Hibiscus sabdariffa* L.) du Niger: évaluations agro morphologique et génétique. Université de Niamey, Niger (2010).
3. Ozer, P., Ozer, Désertification au Sahel: crise climatique ou anthropique. Bull. Séanc. Acad. R. Sci. Outre-Mer Meded. *Zitt. K. Acad. Overzeese Wet*. **51:** pp. 395-423, 2005.
4. Bolanos, J., Edmeades, G. O., CIMMYT Strategies in breeding for drought tolerance in tropical maize. *ln*: Challenges in dry/and agriculture. A global perspective Proc. International Conf. *Dryland farming. Amarillo/Bushland*, 752-4 (1988).
5. Bolanos, J., Edmeades, G. O., Eight cycles of selection for drought tolerance in lowland tropical maize. Il. Responses in reproductive behaviour. *Field Crops Res* **31:** 253-68 (1993b).
6. Brink, M., Development, growth and dry matter partitioning in bambara groundnut (*Vigna subterranea*) as influenced by photoperiod and shading. *Journal of Agricultural. Sciences* **133:** 159-166 (1999).

7. Brink, M., Matching crops and environments: quantifying photo thermal influences on reproductive development in bambara groundnut (*Vigna subterranean* (L.) Verdc). PhD Thesis, Wageningen Agricultural University, Wageningen, Netherlands. 161 pp (1998).
8. Chaudhary, H. K., Kaila, V. and Rather, S. A., Maize. In: Pratap, A. and Kumar, J., Eds. Alien Gene Transfer in Crop Plants: *Achievements and Impacts, Springer, New York*, 27-50. http://dx.doi.org/10.1007/978-1-4614-9572-7-2 (2014).
9. Collinson, S. T., Azam-Ali, S. N., Chavula, K. M. and Hodson, D. A., Growth, development and yield of Bambara groundnut (*Vigna subterranea*) in response to soil moisture. *Journal of Agricultural. Sciences* **126:** 307-318 (1996).
10. Deffan, K. P., Akanvou, L., Akanvou, R., Nemlin, G. J. and Kouamé, P. L., Evaluation morphologique et nutritionnelle de variétés locales et améliorées de maïs (Zea mays L.) produites en Côte d'Ivoire. *Afrique Sciences* **11(3):** 181-196 (2015).
11. Djè, Y., Heuertz, M., Ater, M., Lefebvre, C. and Vekemans, X., Evaluation de la diversité morphologique des variétés traditionnelles de sorgho du Nord-ouest du Maroc. *Biotechnologie, Agronomie, Société et Environnement* **11(1):** 39-46 (2007).
12. Dossou-Aminon, I., Dansi, A., Ahissou, H., Cissé, N., Vodouhè, R. and Sanni, A., Climate variability and status of the production and diversity of sorghum (Sorghum bicolor (L.) Moench) in the arid zone of northwest Benin. *Genetic Resources and Crop Evolution* **63:** 1181-1201 (2015).
13. Elangovan, M., Jain, S. K. and Patel, N. V., Characterization of sorghum germplasm collected from Gujarat. *Indian Journal of Plant Genetic Resources* **26(1):** 42-46 (2013).
14. FAOSTAT, Statistical Database of the Food and Agriculture Organization of the United Nations. FAO, Rome (2010).
15. FAO, Fertilizer and the future. IFA/FAO Agriculture Conference on Global food security and the role of Sustainability Fertilization. Rome, Italy. 16th-20th March, 2003, pp. 1-2 (2003).
16. Fraleigh, B., Importance des banques de ressources phytogénétiques, In: Amélioration et protection des plantes vivrières tropicales, (Eds) Saint Pierre C-A., Demaly, Y., AUPELF UREF, Québec, Canada, 13-18 (1987).
17. Gardner, C. O., Stevens, J., Breeding for stress tolerance in maize. In: Workshop on maize breeding production. *Belgrade, Yugoslavia: Euromaize*, 59-67 (1988).
18. Guengant, J. P., *et* Banoin, M., Dynamique des populations, disponibilités des terres et adaptation des régimes fonciers : le cas du Niger. FAO et Comité International de Coopération dans les Recherches Nationales en Démographie. 144 pages (2003).
19. Harris, D. and Azam-Ali, S. N., Implications of day length sensitivity in Bambara groundnut (*Vigna subterranea*) for production in Botswana. *Journal of Agricultural Sciences* **120:** 75-78 (1993).
20. Karambiri, H., Galiano, S. G. G., Giraldo, J. D., Yacouba, H., Ibrahim, B., Barbier, B., Polcher, J., Assessing the impact of climate variability and climate change on runoff in West Africa: the case of Sénégal and Nakambe River basins. *Atmospheric Science Letters*. **12(1):** pp. 109-115 (2011).
21. Hoisington, D., Khairallah, M., Reeves, T., Ribaut, J. M., Skovmand, B., Taba, S. and War-burton, M., Plant Genetic Resources: What Can They Contribute toward Increased Crop Productivity. *Proceedings of the National Academy of Sciences of the United States of America*, **96:** 5937-5943. http://dx.doi.org/10.1073 /pnas.96.11.5937 (1996).
22. Hoxha, S., Shariflou, M. P., Sharp, P., Evaluation of genetic diversity in Albanian

maize using SSR markers. *Maydica*. **49:** 97-103 (2004).

23. Jaaska, V., Isoenzyme diversity and phylogenetic relationships among the American beans of the genus *Vigna savi* (Fabaceae). *Biochem. Syst. Ecol*. **29:** 1153-1173 (2001).
24. Ekpoh, L. J., Adaptation to the Impact of Climatic Variations on Agriculture by RuralFarmersin North-Western Nigeria. *Journal of Sustainable Development*. **3(4):** pp. 1-9 (2010).
25. Linnemann, A. R., Westphal, E. and Wessel, M., Photoperiod regulation of developmentand growth in Bambara groundnut (*Vigna subterranea*). *Field Crops Research* **40:** 39-47 (1995).
26. Linnemann, A. R. and Craufurd, P. Q., Effects of temperature and photoperiod on phenological development in three genotypes of bambara groundnut (*Vigna subterranea*). *Annals of Botany* **74:** 675-681 (1994).
27. Manzano, A. R., Nodals, R. A. A., Gutiérrez, R. A. I. M., Mayor, F. Z., Alfonso, C. L., Morphologicaland isoenzyme variability of taro (*Colo cassia esculenta* L. Schott) germplasmin Cuba. *Plant Genetic Resources Newsletter*, **126:** 31-40 (2001).
28. Munck, C. D., Modélisation de la végétation urbaine et stratégies d'adaptation pour l'amélioration au confort climatique et de la demande énergétique en ville. Thèse de doctorat, Institut National Polytechnique de Toulouse. Université de Toulouse (France), 219 p (2013).
29. N'da, H. A., Akanvou, L., Kouakou, C. K., Bi Zoro, A. I., Morphological Diversity Local Varieties of Maize (*Zea mays* L.) Collected in the Center and West Center of Ivory Coast. *ESJ*. **10:** 349-362 (2014a).
30. N'da, H. A., Akanvou, L., Akanvou, R., Bi Zoro, A. I., Evaluation of Agro-Morphological Diversity of Accessions Corn (*Zea mays L.*) Collected in Ivory Coast. *J. Anim. Plant Sci*. **20:** 3144-3158 (2014b).
31. Ndiaye, M., Madai, A. and Thiers, R., "Implementing the MAF in Niger: Opportunities and challenges in accelerating MDG 1", Global MDG Conference, *UNDP Working Paper. No*. **8:** UNDP Publishing (2013).
32. Odeleye, F. O., Odeleye, M. O., Evaluation of morphological and agronomic characteristics of two exotic and two adapted varieties of tomato (*Lycopersicom esculentum*) in South West Nigeria. *Proceedings of the 19th Annual Conference of HORTSON*. **1:** 140-145 (2001).
33. Hema, O., Kim, S. K., Mondeil, F., Bakary, B., Tio-Touré, Tapsoba, A., Intervalle entre floraison mâle et femelle chez le maïs: son importance en sélection pour la tolérance à la sécheresse. *Cahiers Agricultures* **10:** 255-60 (2001).
34. Oyekan, J., Vasil, S. K., Beck, D. L., CIMMYT's tropical late yellow maize germplasm. *Maydica* **35:** 273–278 (1990).
35. Richard, M., Zaman-Allah, M., Jill, E.C., Cosmos, M., Amsal, T., Mike, O. and Boddupalli. M. P., High-Throughput Phenotyping of Canopy Cover and Senescence in Maize Field Trials Using Aerial Digital Canopy Imaging. *Remote Sensing* **10(2):** 330; doi:10.3390/rs10020330 (2018).
36. Radhouane, L., Etude de la variabilité morpho-phenologique chez *Pennisetum glaucum* (L.) R. Br., *Plant Genetic Resources Newsletter*, **138:** 18-22 (2004).
37. Rouanet, G., Le technicien d'agriculture tropicale: le maïs, 142 p (1984).
38. Salami, H. A., Adjanohoun, A., Padonou, W., Yacoubou, A., Aly, D., Yallou, C., Sina, H., Baba Moussa, L., Morphological Diversity of Variety Cultivar Local and Improved Corn (*Zea mays* L.) Central and North of Benin. *Am. J. Plant Sci*. **6:** 2867-2877 (2015b).
39. Sanou, A., Création et évaluation hybrides et de lignées de maïs dans le cadre d'une intensification de la maïsiculture au Burkina Faso. Mémoire de fin de cycle,

IDR, UPB, Bobo Dioulasso, Burkina Faso, 80 p (2011).

40. Sanou, J., Variabilité génétique dans les croisements tempérés X exotique chez le maïs. DEA à l'ENSA de Montpellier. France 35 p (1992).
41. Schussler, J. R., Westgate, W. E., Maize kernel at low potential. Sensitivity to reduced assimilates at pollination. *Crop Sci* **31:** 1196- 203 (1991).
42. Smith, S. E., Doss, A. A., Warburton, M., Morphological and agronomic variation in North African and Arabian alfalfas, *Crop Science*, **31:** 1159-1163 (1991).
43. Smith, J., Barau, A. D., Goldman, A., Mareck, J. H., The role of technology in agricultural intensification: The evolution of maize production in the Northern Guinea Savanna of Nigeria. *Econ. Dev. Cult Change* **42(3):** 537-554 (1994).
44. Undersander, D. J., Yield and yield component response of maize to water stress in hybrids with different sources of stress tolerance. *Maydica* **32:** 49-60 (1987).
45. Von Braun, J., Byerlee, D., Chartres, C., Lumpkin, T., Olembo, N. and Waage, J. J., A Draft Strategy and Results Framework for the CGIAR. World Bank, CGIAR, Washington DC (2010).
46. World Bank Agriculture Investment Sourcebook. Agriculture and Rural Development. World Bank, Washington DC (2005).
47. Yan, W., Tinker, A., Biplot analysis of multi environment trial data: principles and applications. *Canadian Journal of Plant Science*, **86:** p. 623-645 (2006).
48. Yobi, A., Henchi, B., Neffati, M., Jendoubi, R., Système de reproduction et variabilité morphophenologique chez *Allium roseum*, *Plant Genetic Resources Newsletter*, **127:** 29-34 (2002).