



## Drought tolerance in F<sub>1</sub> interspecific hybrid between, *Solanum melongena* and its wild ancestor, *Solanum insanum*

Brice Aymar K. KOUASSI, Germain DROH<sup>\*</sup>, Abou Bakari KOUASSI,  
Richard Armand Kouadio AKA and Simon-Pierre Assanvo N'GUETTA

Laboratory of Biotechnologies, Agriculture and Development of Biological Resources, UFR Biosciences,  
University Felix Houphouët-Boigny (UFHB), 22 BP 582, Abidjan 22, Côte d'Ivoire.

<sup>\*</sup>Corresponding author; E-mail: [drohge7@yahoo.fr](mailto:drohge7@yahoo.fr), Phone: +225 07 070 721 55 13

Received: 30-10-2021

Accepted: 15-06-2022

Published: 30-06-2022

### ABSTRACT

The need for improved aubergine varieties is increasing because of climate change's effects such as drought. To solve this problem, the use of wild ancestor of aubergine, *Solanum insanum*, as a source of genes seems appropriate since this species is found in various climates. The objective was to obtain aubergine genotypes with genes from the wild species, *S. insanum*, giving them the ability to adapt to drought. Drought tolerance of accessions from *Solanum melongena* and *Solanum insanum* and their F<sub>1</sub> progeny was assessed using 16 phenotypic descriptors. Variance and genetic parameters (heritability ( $h^2$ ), genotypic (GCV) and phenotypic (PCV) coefficients of variation, correlations) relating to growth dynamics were estimated. F<sub>1</sub> hybrids exhibited better drought tolerance abilities than parental accessions. The values of floral characteristics of these hybrids were higher in dry season. This favoured reproduction at expense of vegetative growth. Finally, high differences between GCV and PCV corroborated by low values of  $h^2$  show that plant selection based on growth dynamics would be ineffective for improving aubergine against drought. Development of plant organs determined by genes with pleiotropic effects is reflected by contrasting values of genotypic and phenotypic correlations.

© 2022 International Formulae Group. All rights reserved.

**Keywords:** *Solanum melongena*, *Solanum insanum*, drought tolerance, heterosis effect, genetic parameters.

### INTRODUCTION

Aubergine, *Solanum melongena*, is an important vegetable plant, particularly in the tropics and subtropics of the world. It is one of the 35 crops considered most important for food security and, as such, is included in Annex 1 of the International Treaty on Plant Genetic Resources for Food and Agriculture (Fowler et al., 2003). *Solanum insanum*, the closest wild ancestor of *S. melongena*, is found on different continents such as Africa and Asia as well as in a wide range of climatic conditions (Knapp et

al., 2013; Vorontsova and Knapp, 2016; Ranil et al., 2017). This species has mainly been subjected to natural selection and the indirect effect of human activities. It has therefore not suffered a bottleneck due to domestication and selection by humans. *S. insanum* would therefore present a large allelic variation for important agronomic characters as well as for adaptation to various environmental conditions. Thus, it could play a major role in the improvement of *S. melongena*.

Aubergine genotypes capable of adapting to changing environmental conditions are few, or even non-existent. Indeed, none of the commercial varieties of aubergine show introgressions of genes from the wild ancestor *S. insanum*. However, the need for improved aubergine varieties is increasing with the challenges imposed by the effects of climate change such as droughts. In times of drought, crop production is subject to reduced yields, increased production costs and deterioration in cultivation practices. In a context where water resources are already scarce and are likely to become scarcer, irrigation, as a means of alleviating drought, has its own environmental and economic costs. This option therefore appears to be unsuitable for all scenarios; hence the need to find effective means to increase or at least stabilize crop production in the face of new challenges due to climate change in order to guarantee food security.

One of the means used is the genetic improvement of plants. It consists in obtaining improved varieties that are well adapted to the restrictive conditions of the environment. In particular for the cultivation of aubergine, obtaining varieties with a capacity for tolerance or resistance to drought appears to be a promising way to deal with this problem. To do this, the use of the wild ancestor of aubergine, *S. insanum*, as a source of genes of agronomic interest in breeding and variety creation programs appears to be well suited (Kashyap et al., 2003; Daunay and Hazra, 2012). Sexual hybridization techniques between related species can be an advantage in rapidly adapting to the challenges of biotic and abiotic stresses. These techniques could provide genotypes with new combinations of genes to cope with new environmental conditions (Becker et al., 2013; Henry, 2014). With a view to improving *S. melongena* for its adaptation to future challenges facing its culture, in this case drought, sexual hybridization has been carried out. The use of interspecific hybridization between *S. melongena* and its wild ancestor, *S. insanum*, allowed introgressions of genes of this species in *S. melongena* (Kouassi et al., 2016; Plazas et al., 2016). Obtaining these new genotypes leads to the expansion of genetic

variability within the species *S. melongena*. New genotypes obtained by sexual hybridization techniques can be characterized and evaluated phenotypically. The dispersion parameters of the phenotypic and genotypic data such as the phenotypic and genotypic coefficients of variation give indications on the level of variability of the phenotypic performances due to the differences between the phenotypes and the genotypes, but do not indicate the heritable and non-heritable part of this variability (Sawadogo et al., 2016; Gai and Lu, 2013). In fact, the higher the heritability ( $h^2$ ) of the traits, the more effective the selection is and the association of the phenotypic (PCV) and genotypic (GCV) coefficients of variation with heritability provides better information on the prediction of phenotypic performance (Kabr e et al., 2019; Afful et al., 2020). It's in this sense that this study analyses the morphogenetic characteristics of two accessions of the species *S. melongena* and *S. insanum*, their interspecific hybrid descendants ( $F_1$ ) for drought tolerance. The objective was to obtain aubergine genotypes with genes from the wild species, *S. insanum*, giving them the ability to adapt to drought.

## MATERIALS AND METHODS

### Study site and plant material

This study was carried out in a research station in Abidjan in the south of C te d'Ivoire. All the crosses and agro-morphological characterizations in field conditions were carried out on the experimental plots of the general management of the National Agronomic Research Centre (CNRA) of C te d'Ivoire located in Adiopodoum  17 km from Abidjan. The geographical coordinates of the experimental field are 5 ° 19 '516 "North latitude; 4 ° 08' 206" West longitude with an altitude of 37 m. The climate of Abidjan is characterized by four seasons, including two rainy seasons and two dry seasons.

The plant material used for this study consists of the 7145 accessions of *S. melongena* (Figure 1) and the MM 498 accessions of *S. insanum* (Figure 2) as well as the interspecific hybrid progeny ( $F_1$ ) between

the accession *S. melongena* and that of *S. insanum* (Table 1).

## Methods

### Production of F1 hybrid progenies

Manual hybridizations were carried out between the accessions (7145 of *S. melongena* and MM 498 of *Solanum insanum*) to obtain interspecific hybrids (F<sub>1</sub>) (Kouassi, 2019; Figure 3). The accession of *S. melongena* has been used as a female parent in performing interspecific hybridizations.

### Agro-morphological character measurements

Plants were characterized from 16 agro-morphological characters derived from the aubergine descriptor (IBPGR, 1990). These characters are distributed as follows: three architectural parameters of the plant, four leaf parameters, four flowering parameters and five characteristics of the fruit (Table 2). The measurements of vegetative growth traits were made 3 and 10 weeks after transplanting the seedlings to the field (coded respectively 3 SAR and 10 SAR). Floral characters were evaluated on three to four inflorescences selected at random per plant. When the inflorescence consists of more than 3 flowers, the stamens were counted on 3 flowers also chosen at random. Fruit characters were measured on 3 to 4 fruits per plant.

### Data analysis

The development rates of the vegetative growth parameters (height, width and branching of the plant, length and width of the blade, length and thickness of the petiole) were calculated to evaluate the growth dynamics of the plants according to the following formula:

$$\frac{(\text{Average vegetative growth parameter at 10SAR} - \text{average vegetative growth parameter at 3SAR})}{\text{average vegetative growth parameter at 3SAR}}$$

The drought tolerance of each genotype was also assessed through the calculation of drought tolerance scores for each vegetative growth and production parameter through the reports:

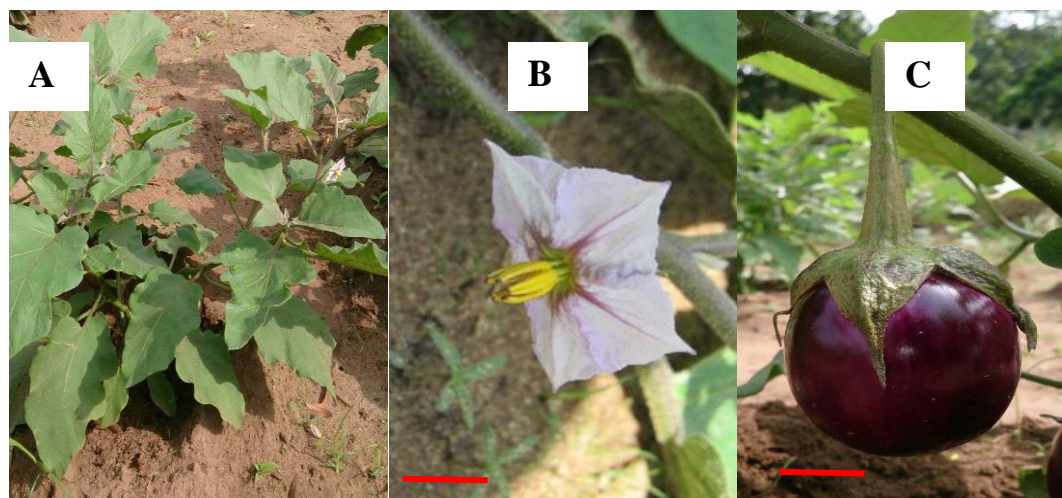
$$\frac{\frac{\text{Rainy season development rate}}{\text{Dry season development rate}}, \text{ for vegetative growth parameters and } \frac{\text{Average value of the production parameter in the rainy season}}{\text{Average value of the production parameter in the dry season}}}$$

for production characteristics (Kouassi et al., 2020). The resulting drought tolerance scores were compared to the baseline 1 using a single sample t test. For each of the agro-morphological characteristics measured, when the ratio between the data obtained in the rainy season and those obtained in the dry season is equal to 1, this means that the genotype considered has similar values during the two seasons. When this ratio is greater than 1, this indicates that the genotype considered has a higher value for this characteristic in the rainy season. When this ratio is less than 1, it means that the value of this characteristic in the dry season is higher than that obtained in the rainy season. The genotype was considered to be drought tolerant when the score obtained is less than or equal to the reference value 1 (Kouassi et al., 2020). All statistical analyses were performed using IBM SPSS Statistics 22.0 software (IBM corp. Armonk, NY, USA). The variance component estimates were performed using a linear mixed model based on the Restricted Maximum Likelihood Method (REML) (Patterson and Thompson, 1971; Kruuk, 2004; Mrode, 2005). The calculations of the variance - covariance matrices as well as the matrices of genotypic and phenotypic correlations were made using the Variance Components Estimation (VCE) package, version 6.0.2 (Groeneveld et al., 2010).

The variance - covariance matrices provided by the VCE 6.0.2 package allowed the calculation of heritability in the strict sense (h<sup>2</sup>) as well as the phenotypic (PCV) and genotypic (GCV) coefficients of variation. GCV and PCV are low when values are less than 11%, moderate between 11 and 20% and high for values greater than 20% (Sumathi et al., 2010). The formulas for the calculation of genetic parameters are as follows:

$$h^2 = \frac{\sigma_a^2}{\sigma_p^2}, \text{ PCV} = \left( \frac{\sqrt{\sigma_p^2}}{\mu} \right) \times 100, \text{ GCV} = \left( \frac{\sqrt{\sigma_a^2}}{\mu} \right) \times 100 \text{ et } r = \frac{\text{cov}(x,y)}{\sqrt{\sigma_x^2 \times \sigma_y^2}}$$

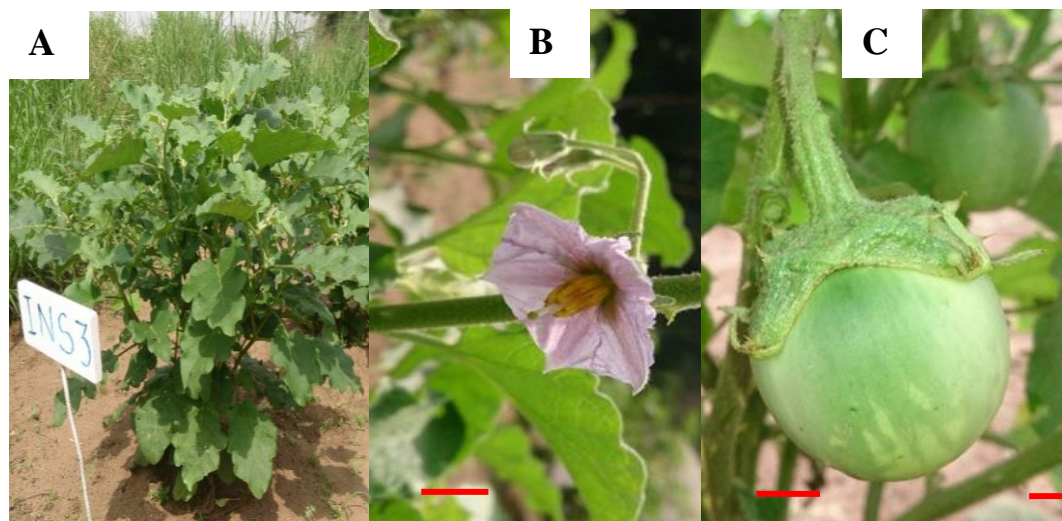
Where:  $\sigma_a^2$  is the additive variance and  $\sigma_p^2$  the phenotypic variance,  $\mu$  the character average;  $\text{cov}(x, y)$  is the covariance between 2 characters x and y,  $\sigma_x^2$  is the variance of the character x and  $\sigma_y^2$  is the variance of the character y.



**Figure 1:** Accession 7145 (code MEL4) of aubergine, *Solanum melongena*.

A: Plant, B: flower and C: fruit.

**Scale:** the bar of image A represents 10 cm in reality, the bar of image B represents 2 cm in reality and the bar of image C represents 5 cm in reality



**Figure2:** Accession MM 498 (INS3 code) of *Solanum insanum*, wild ancestor of aubergine, *Solanum melongena*.

A: Plant, B: flower and C: fruit.

**Scale:** the bar of image A represents 10 cm in reality, the bar of image B represents 2 cm in reality and the bar of image C represents 5 cm in reality

**Table 1:** Parental accessions and interspecific hybrid offspring (F<sub>1</sub>) whose phenotypic characteristics were measured in the field.

Species	Accession	Code	Generation	Origin
<i>S. melongena</i>	7145	MEL4	P	Sri-Lanka
<i>S. insanum</i>	MM 498	INS3	P	Japon
-	7145 x MM 498	MEL4 x INS3	F <sub>1</sub>	-

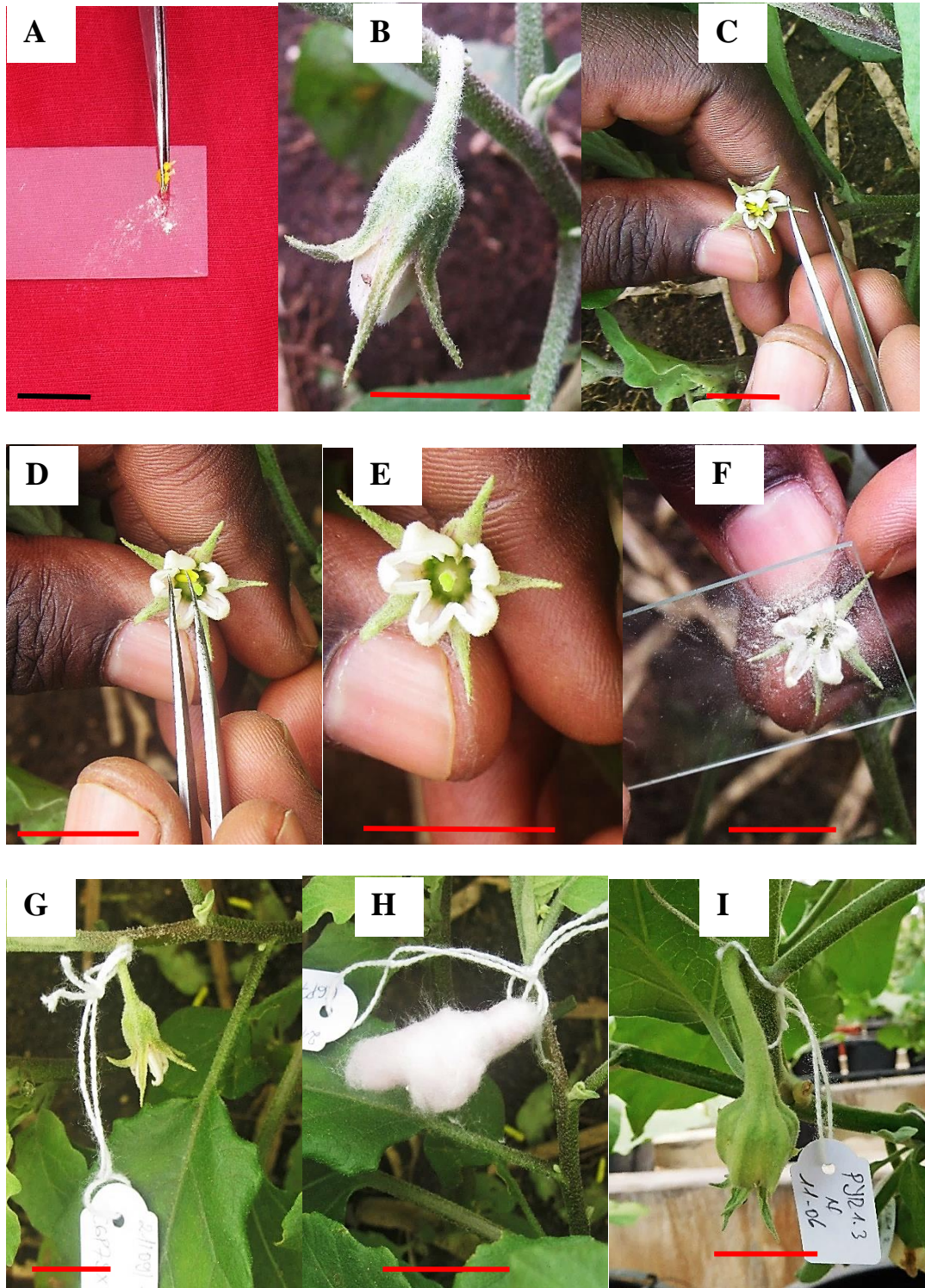
P : parental accessions, F<sub>1</sub> : interspecific hybrid

**Table 2:** Agro-morphological descriptors used for the phenotypic characterization of parental accessions and interspecific hybrid progeny.

N°	Descriptor	Unit (SI)	Code	Organ	Descriptor type
1	Plant height	cm	HTPL		
2	Plant width	cm	LGPL	Plant	
3	Number of Branches	—	RAM		
4	Leaf blade length	cm	LLIM		Vegetative growth
5	Leaf blade width	cm	LGLIM	Sheet	
6	Petiole length	cm	LPET		
7	Petiole thickness	mm	EPET		
8	Flowering time		TFLO		
9	Number of flowers / inflorescence	—	NFLIN	Floral phenology	
10	Relative length of style		LRSTY		
11	Number of stamens	—	NETA		
12	Length of the fruit	cm	LFR		Production
13	Width of the fruit	cm	LGFR		
14	Length of the pedicel of the fruit	cm	LPFR	Fruit	
15	Fruit pedicel thickness	mm	EPFR		
16	Fruit mass	g	MFR		

SI : International system





**Figure 3:** Different stages of carrying out manual pollination in aubergine.

**A:** collection of pollen from the stamens of the plant chosen as the male parent; **B:** choice of a flower bud from the plant used as the female parent; **C:** opening of the flower bud; **D:** emasculation of the flower chosen as female; **E:** emasculated flower; **F:** Manual pollination; **G:** labelling; **H:** isolation of the pollinated flower; **I:** Setting of the flower pollinated manually.

Scale: each bar represents 2 cm in reality; Source Kouassi, 2019.

## RESULTS

### Drought tolerance of agro-morphological characteristics in interspecies hybrid and parental accessions

The MEL4 x INS3 interspecific hybrid offspring had drought tolerance scores ( $R_1$ ) less than or equal to 1 ( $R_1 \leq 1$ ). These hybrids therefore exhibited faster vegetative growth in the dry season than in the rainy season. On the other hand, with the exception of plant height (HTPL) and petiole thickness (EPET), interspecific hybrids exhibited smaller values which indicate better drought tolerance scores ( $R_1 < 1$ ) than the parental accessions INS3 and MEL4 (Table 3). For both the interspecific hybrid and the parental accessions INS3 and MEL4,

Flowering time (TFLO) was shorter in the dry season than in the rainy season ( $R_2 < 1$ ). Flower characteristic values of number of flowers per inflorescence (NFLIN) and relative style length (LRSTY) were higher in the dry season than in the rainy season. However, the F1 hybrid progeny exhibited better drought tolerance scores ( $R_2 = 1$ ) than the parental accessions INS3 and MEL4 ( $R_2 > 1$ ) (Table 4). With the exception of fruit mass (MFR), the interspecific hybrid showed lower values of fruit characteristics in the dry season than in the rainy season. Drought tolerance scores on fruit length and width (LFR and LGFR) were better ( $R_2 = 1$ ) in the interspecific hybrid. Drought tolerance scores of fruit pedicel length and fruit mass (LPEFR and MFR) on the one hand and fruit pedicel thickness (EPEFR) on the other were better in parental accessions INS3 and MEL4 (Table 4).

### Estimates of variance components and genetic parameters related to the growth dynamics of vegetative growth characteristics

The coefficients of phenotypic variation (PCV) were higher than the coefficients of genotypic variation (GCV) for the development rates of vegetative growth traits. GCV values range from 19.99% for plant width development rate (LGPL) to 56.40% for leaf

petiole thickness development rate (EPET). The lowest PCV value was 45.65% for branch development rate (RAM). The differences between PCV and GCV ranged from 14.83% for the branch development rate (RAM) to 122.54% for the petiole length development rate (LPET). These differences were generally high (Table 5).

Heritability values for development rates of vegetative growth parameters were all less than 0.50. Indeed, the highest heritability value (0.46) was observed for the rate of branching development. The lowest values of heritability were observed for the rate of development of the length of the petiole (0.04) as well as the height (0.07) and the width (0.10) of the plant (Table 5). No significant phenotypic correlation was observed between development rates of plant height (HTPL), width (LGPL) and branching (RAM) and development rates of other vegetative growth parameters. The genotypic correlations were overall negative.

However, the rate of development of plant height (HTPL) was positively correlated with those of plant width ( $r_g = 0.99$ ) and petiole length ( $r_g = 0.71$ ). The plant width development rate (LGPL) was also positively correlated with that of petiole length ( $r_g = 0.71$ ). Positive genotypic correlations were also observed between the rate of branching development and those of length ( $r_g = 0.91$ ) and width of the blade ( $r_g = 0.92$ ), and thickness of the petiole ( $r_g = 0.91$ ) (Table 6). The phenotypic correlation coefficients ( $r_p$ ) between the development rates of blade length and width (LLIM and LGLIM), petiole length and thickness (LPET and EPET) were positive and all greater than 0, 50. The genotypic correlations between the development rates of these parameters were also very strong. They were greater than 0.90 with the exception of those between the rate of development of the length of the petiole (LPET) and respectively those of the length of the blade ( $r_g = 0.06$ ), of the width of the blade ( $r_g = 0.08$ ) and the thickness of the petiole ( $r_g = 0.11$ ) (Table 6).

**Table 3:** Drought tolerance scores for vegetative growth characteristics in INS3 and MEL4 accessions and their interspecific hybrid progeny.

		Genotypes		
		INS3	MEL4	MEL4 x INS3
<b>HTPL</b>	Tolerance score (R1)	<b>0.58</b>	<b>0.99</b>	<b>0.71</b>
	T; (P)	-4.02; (0.06)	0.32; (0.78)	-0.89; (0.47)
<b>LGPL</b>	Tolerance score (R1)	<b>0.77</b>	<b>0.66</b>	<b>0.39</b>
	T; (P)	-1.35; (0.31)	-0.76; (0.53)	-4.36; (0.05)
<b>RAM</b>	Tolerance score (R1)	2.84	<b>1.33</b>	<b>0.70</b>
	T; (P)	86.00; (0.00)	2.60; (0.12)	1.09; (0.39)
<b>LLIM</b>	Tolerance score (R1)	<b>0.66</b>	<b>0.94</b>	<b>0.06</b>
	T; (P)	-0.49; (0.67)	0.84; (0.49)	-52.37; (0.00)
<b>LGLIM</b>	Tolerance score (R1)	<b>0.47</b>	<b>0.63</b>	<b>0.02</b>
	T; (P)	-4.20; (0.05)	0.52; (0.66)	-63.61; (0.00)
<b>LPET</b>	Tolerance score (R1)	2.63	6.74	<b>0.11</b>
	T; (P)	14.06; (0.01)	89.16; (0.00)	-33.12; (0.00)
<b>EPET</b>	Tolerance score (R1)	3.17	<b>0.50</b>	<b>0.67</b>
	T; (P)	-17.12; (0.00)	9.21; (0.01)	-0.11; (0.92)

In bold, the R1 ratio values significantly less than or equal to 1; T: value of the statistic associated with Student's t test; P: probability value associated with Student's t test. R1 = 1, signifies that the considered genotype has similar values during the 2 seasons; R1 <1, signifies that the value of this characteristic in the dry season is higher than that obtained in the rainy season; R1 > 1, indicates that the value of this characteristic in the rainy season is higher than that obtained in the dry season.

**Table 4:** Drought tolerance scores of production parameters in INS3 and MEL4 accessions and their interspecific hybrid progeny.

		Genotypes		
		INS3	MEL4	MEL4 x INS3
<b>TFLO</b>	Tolerance score (R2)	<b>1.27</b>	<b>1.11</b>	<b>1.08</b>
	T; (P)	0.51; (0.66)	1.98; (0.19)	1.52; (0.27)
<b>NFLIN</b>	Tolerance score (R2)	<b>0.86</b>	<b>1.20</b>	<b>0.84</b>
	T; (P)	-1.66; (0.24)	0.65; (0.58)	-1.96; (0.19)
<b>LRSTY</b>	Tolerance score (R2)	<b>0.93</b>	<b>1.07</b>	<b>0.11</b>
	T; (P)	0.75; (0.53)	0.51; (0.66)	-5.00; (0.04)
<b>NETA</b>	Tolerance score (R2)	<b>0.96</b>	<b>1.16</b>	<b>1.11</b>
	T; (P)	-0.24; (0.83)	-1.43; (0.29)	-0.07; (0.95)
<b>LFR</b>	Tolerance score (R2)	<b>1.26</b>	<b>1.20</b>	<b>1.06</b>
	T; (P)	3.39; (0.08)	0.66; (0.58)	0.91; (0.46)
<b>LGFR</b>	Tolerance score (R2)	<b>1.35</b>	<b>1.28</b>	<b>1.08</b>
	T; (P)	-3.81; (0.06)	0.93; (0.45)	2.60; (0.12)
<b>LPEFR</b>	Tolerance score (R2)	<b>0.58</b>	<b>0.87</b>	<b>1.23</b>
	T; (P)	-3.51; (0.07)	1.80; (0.21)	1.78; (0.22)
<b>EPEFR</b>	Tolerance score (R2)	<b>1.54</b>	<b>0.16</b>	<b>1.10</b>
	T; (P)	5.28; (0.03)	-97.00; (0.00)	1.98; (0.19)
<b>MFR</b>	Tolerance score (R2)	<b>0.51</b>	<b>1.36</b>	<b>0.63</b>
	T; (P)	-31.63; (0.00)	2.48; (0.13)	1.13; (0.38)

In bold, the R2 ratio values significantly less than or equal to 1; T: value of the statistic associated with Student's t test; P: probability value associated with Student's t test. R2 = 1, signifies that the considered genotype has similar values over the 2 seasons; R2 <1, means that the value of this characteristic in the dry season is higher than that obtained in the rainy season; R2 > 1, indicates that the value of this characteristic in the rainy season is higher than that obtained in the dry season.



**Table 5:** Variance components, mean values and genetic parameters of development rates of vegetative growth characteristics.

	$\sigma^2_a$	$\sigma^2_p$	$\mu$	GCV (%)	PCV (%)	Deviation (PCV-GCV)	$h^2 \pm ES$
<b>HTPL</b>	0.82	11.06	2.48	36.62	134.18	97.57	0.07 ± 0.09
<b>LGPL</b>	0.24	2.33	2.43	19.99	62.80	42.80	0.10 ± 0.05
<b>RAM</b>	1.18	2.59	3.52	30.82	45.65	14.83	0.46 ± 0.36
<b>LLIM</b>	0.24	0.87	1.05	46.04	88.50	42.46	0.27 ± 0.31
<b>LGLIM</b>	0.21	0.72	0.88	52.41	96.41	44.00	0.30 ± 0.41
<b>LPET</b>	0.02	0.49	0.46	30.06	152.61	122.54	0.04 ± 0.27
<b>EPET</b>	0.15	0.60	0.68	56.40	113.66	57.26	0.25 ± 0.36

$\sigma^2_a$ : additive variance,  $\sigma^2_p$ : phenotypic variance,  $\mu$ : character average, GCV: coefficient of genotypic variation, PCV: coefficient of phenotypic variation,  $h^2$ : heritability in the narrow sense, ES: standard error.

**Table 6:** Genotypic and phenotypic correlation coefficients between development rates of vegetative growth parameters.

	<b>HTPL</b>	<b>LGPL</b>	<b>RAM</b>	<b>LLIM</b>	<b>LGLIM</b>	<b>LPET</b>	<b>EPET</b>
<b>HTPL</b>	1	<b>0.99</b>	<b>-0.77</b>	<b>-0.62</b>	<b>-0.60</b>	<b>0.71</b>	<b>-0.57</b>
<b>LGPL</b>	0.13	1	<b>-0.77</b>	<b>-0.62</b>	<b>-0.60</b>	<b>0.71</b>	<b>-0.57</b>
<b>RAM</b>	-0.07	0.02	1	<b>0.91</b>	<b>0.92</b>	-0.23	<b>0.91</b>
<b>LLIM</b>	0.12	0.33	0.05	1	<b>0.99</b>	0.06	<b>0.99</b>
<b>LGLIM</b>	0.12	0.29	0.02	<b>0.93</b>	1	0.08	<b>0.99</b>
<b>LPET</b>	0.13	0.31	-0.21	<b>0.66</b>	<b>0.63</b>	1	0.11
<b>EPET</b>	0.09	0.27	0.05	<b>0.86</b>	<b>0.80</b>	<b>0.61</b>	1

The genotypic correlation coefficients in the upper triangle and the phenotypic correlation coefficients in the lower triangle; in bold, the correlation coefficients greater than 0.5 in absolute value.

**DISCUSSION**

For all vegetative growth parameters, the F1 hybrids exhibited better drought tolerance scores (less than 1) than those of the parental accessions MEL4 and INS3. The work of Prohens et al. (2012), Kaushik et al. (2016) as well as the results of the present study showed, for vegetative growth characteristics, the existence of a heterosis effect in

interspecific hybrids between eggplant and related wild species. This vigorous vegetative growth could explain the fact that the hybrid MEL 4 x INS3 expresses drought tolerance abilities. According to Clavel et al. (2005) and Toudou et al. (2017), these good drought tolerance skills could result from the maintenance, in the plant, of important physiological functions such as growth when

drought sets in. This is a strategy that is therefore induced in that it would only develop when the plant is facing water stress. Both for the interspecific hybrid and for parental accessions, early flowering was observed in the dry season compared to the rainy season. This observed precocity could be explained by an induction of flowering when drought occurs.

Indeed, like many plants, seasonal variations in temperature and hygrometric variations are likely to trigger flowering in aubergine (Hamès, 2008; Ubi et al., 2014). In addition to the early flowering, the interspecies hybrid had floral characteristics such as the number of flowers per inflorescence and the relative length of the style higher in the dry season than in the rainy season.

Thus, the dry season imposes stress conditions such as heat and reduced water availability in the soil, the perception of which by the plant could trigger a survival mechanism. This mechanism would cause the plant to promote reproduction to the detriment of vegetative development, hence the early onset of flowering and the increase in floral characteristics. Increasing these parameters could lead to increased fruit production in the plant. However, the interspecific hybrid MEL4 x INS3 and parental accessions produced smaller fruits in the dry season than in the rainy season. This reduction in the size of the fruit in the dry season could be explained by the fact that after fertilization of the flower and obtaining the fruit, the plant needs water for its proper development (Hou et al., 2020).

The values of the phenotypic coefficients of variation (PCV) were higher than those of the genotypic coefficients of variation (GCV) for the development rates of vegetative growth traits between the 3rd and the 10th week after planting. These gaps were generally high. These high differences between PCVs and GCVs reflect a strong influence of the environment on growth dynamics. These high differences between GCVs and PCVs were corroborated by relatively low values of heritability in the strict sense which further suggest that selection of plants on the basis of development rates of vegetative growth parameters would be inefficient for the plant,

improvement of the aubergine in the face of restrictive environmental conditions. Correlation data is used to estimate the values of other traits when selection is applied to a given trait (Gai and Lu, 2013). Overall, positive phenotypic and genotypic correlations were observed between the development rates of leaf characteristics. Thus, a selection targeting for example an improvement in the growth rate of the length of the blade will lead to an increase in the growth rate of the other leaf parameters. In contrast, genotypic correlations were generally negative between the rates of branch development and those of plant height and width. This means that a selection for increasing the speed of growth in height of the plant for example it will lead to a reduction in that of branching. These contrasting values of the correlation coefficients reflect the fact that all the organs of each plant do not have the same development dynamic, but ultimately reach characteristic dimensions which are determined by genes with pleiotropic effects and / or presenting complex interactions.

## Conclusion

The objectives of this study were first to assess the drought tolerance of parental accessions and their F1 offspring. And second to estimate the components of variance and genetic parameters namely, heritability, genotypic coefficients of variation, and phenotypic, the genetic and phenotypic correlation coefficients relating to the growth dynamics of vegetative growth characteristics. For all vegetative growth parameters, the F1 hybrid exhibited better drought tolerance abilities than the parental accessions MEL4 and INS3. Regarding the production parameters, both for the interspecific hybrid and for the parental accessions, it was observed an early flowering in the dry season compared to the rainy season. This could therefore be explained by an induction of flowering when drought occurs. In addition, the interspecific hybrid had floral characteristics such as the number of flowers per inflorescence and the relative length of the style higher in the dry season than in the rainy season, which would

cause the plant to favour reproduction at the expense of the vegetative development hence the early onset of flowering and the increase in floral characteristics. Although the interspecific hybrid MEL4 x INS3 and parental accessions produced smaller fruits in the dry season than in the rainy season, increasing these parameters could lead to increased fruit production in the plant. Finally, the high differences between the GCVs and the PCVs corroborated by relatively low values of heritability in the strict sense show that the selection of plants on the basis of the development rates of the vegetative growth parameters would be ineffective for the improvement of the heritability. Aubergine in the face of restrictive environmental conditions. Negative phenotypic and genotypic correlations were observed between the rates of development of vegetative growth characteristics between the 3<sup>rd</sup> and the 10<sup>th</sup> week after planting. These contrasting values of the correlation coefficients reflect the fact that all the organs of each plant do not have the same development dynamics, but their final characteristic dimensions are determined by genes with pleiotropic effects and / or with complex interactions.

### COMPETING INTERESTS

The authors declare that they have no competing interests.

### AUTHORS' CONTRIBUTIONS

BAKK performed research and wrote the first draft of the manuscript; GD analyzed the data and wrote the manuscript; ABK analyzed the data and conceived the study; RAKA collected data on field; S-PAN supervised the study. BAKK and GD wrote the manuscript, and the co-authors corrected it.

### ACKNOWLEDGMENTS

This work was undertaken as part of the initiative "Adapting Agriculture to Climate Change: Collecting, Protecting and Preparing Crop Wild Relatives", which is supported by the Government of Norway. The project is managed by the Global Crop Diversity Trust with the Millennium Seed Bank of the Royal

Botanic Gardens, Kew and implemented in partnership with national and international gene banks and plant breeding institutes around the world. For further information see the project website: <http://www.cwrdiversity.org/>. The authors would like to thank Prof. Jaime Prohens, for their technical help throughout several stages of the research.

### REFERENCES

- Afful NT, Nyadanu D, Akromah R, Amoatey HM, Oduro V, Annor C. 2020. Gene effect and heritability of yield and its components in eggplant. *African Crop Science Journal*, **28** (2): 227 – 239. DOI: <https://dx.doi.org/10.4314/acsj.v28i2.8>.
- Becker M, Gruenheit N, Steel M, Voelckel C, Deusch O, Heenan PB, McLenach PA, Kardailsky O, Lockhart PJ. 2013. Hybridization may facilitate *in situ* survival of endemic species through periods of climate change. *Nature Climate Change*, **3** (12) : 1039 -1043. DOI : <https://doi.org/10.1038/nclimate2027>.
- Clavel D, Drame NK, Diop ND, Zuily-Fodil Y. 2005. Adaptation à la sécheresse et création variétale : le cas de l'arachide en zone sahélienne, 1ère partie revue bibliographique. *OCL. Oléagineux Corps gras Lipides*, **12** (3): 248-260. DOI: <http://dx.doi.org/10.1051/ocl.2005.0248>.
- Daunay MC, Hazra P. 2012. Eggplant. In *Handbook of Vegetables*, Peter KV, Hazra P (Eds). Studium Press: Houston, Tx; 257 - 322.
- Fowler C, Moore G, Hawtin GC. 2003. *The International Treaty on Plant Genetic Resources for Food and Agriculture: A Primer for the Future Harvest Centres of the CGIAR*. International Plant Genetic Resources Institute: Rome, Italy.
- Gai J, Lu J. 2013. Quantitative genetics. *Brenner's Encyclopedia of Genetics* (2nd Edn), Stranley M, Kelly H (eds). Academic Press; 13-17. DOI: <https://doi.org/10.1016/B978-0-12-374984-0.01249-3>.
- Groeneveld E, Kovač M, Mielenz N. 2010. VCE v6.0. User's Guide and Reference

- Manual Version 6.0.  
<ftp://ftp.tzv.fal.de/pub/vce6/doc/vce6-manual-3.1-A4.Pdf>.
- Hamès C. 2008. Etude fonctionnelle et structurale du régulateur floral LEAFY d'*Arabidopsis thaliana*. Thèse de Doctorat en Biologie végétale, Université Joseph-Fourier - Grenoble I, Grenoble, p. 162. HAL Id: tel-00492019.
- Henry RJ. 2014. Genomics strategies for germplasm characterization and the development of climate resilient crops. *Frontiers in Plant Science*, **5** (68). DOI: 10.3389/fpls.2014.00068.
- Hou X, Zhang W, Du T, Kang S Z, Davies WJ. 2020. Responses of water accumulation and solute metabolism in tomato fruit to water scarcity and implications for main fruit quality variables. *Journal of Experimental Botany*, **71** (4): 1249–1264. DOI:10.1093/jxb/erz526.
- International Board of Plants Genetics Resources (IBPGR), 1990. Descriptors for eggplant / Descripteurs pour l'aubergine. Rome, p.23.
- Kabré NV, Sawadogo B, Kiébré M, Kiébré Z, Nanema RK, Bationo-Kando P. 2019. Estimates of phenotypic diversity and genetic parameters of *Hibiscus cannabinus* L. grown in Burkina Faso. *International Journal of Biological and Chemical Sciences*, **3** (4): 1903-1917. DOI: <https://dx.doi.org/10.4314/ijbcs.v13i4.1>.
- Kashyap V, Kumar SV, Collonnier C, Fusarin F, Haicour R, Rotino GL, Sihachakr D, Rajam M. 2003. Biotechnology of eggplant. *Scientia Horticulturae*, **97** (1): 1-25. DOI: [https://doi.org/10.1016/S0304-4238\(02\)00140-1](https://doi.org/10.1016/S0304-4238(02)00140-1)
- Kaushik P, Prohens J, Vilanova S, Gramazio P, Plazas M. 2016. Phenotyping of eggplant wild relatives and interspecific hybrids with conventional and phenomics descriptors provides insight for their potential utilization in breeding. *Frontiers in Plant Science*, **7** (may 2016): 1-16. DOI: 10.3389/fpls.2016.00677
- Knapp S, Vorontsova MS, Prohens J. 2013. Wild relatives of the eggplant (*Solanum melongena* L.: Solanaceae): new understanding of species names in a complex group. *PLoS ONE*, **8** (2): 1-12. DOI: 10.1371/journal.pone.0057039
- Kouassi AB, Kouassi KBA, Zakaria S, Plazas M, Fonseka RM, Kouassi A, Fonseka H, N'guetta AS-P, Prohens J. 2020. Genetic parameters of drought tolerance for agromorphological traits in eggplant, wild relatives, and interspecific hybrids. *Crop Science*, **61** (1): 55-68. DOI: <https://doi.org/10.1002/csc2.20250>.
- Kouassi B, Prohens J, Gramazio P, Kouassi AB, Vilanova S, Galán-Ávila A, Herraiz FJ, Kouassi A, Seguí-Simarro JM, Plazas M. 2016. Development of backcross generations and new interspecific hybrid combinations for introgression breeding in eggplant (*Solanum melongena*). *Scientia Horticulturae*, **213**: 199 – 207. DOI: <http://doi.org/10.1016/j.scienta.2016.10.039>.
- Kouassi KBA. 2019. Caractérisation agromorphologique et génétique de l'aubergine cultivée (*Solanum melongena*L.), de 13 espèces apparentées et leurs hybrides pour l'adaptation à la sécheresse en Côte d'Ivoire. Thèse de doctorat en génétique et amélioration des plantes. Université Félix Houphouët-Boigny, Abidjan, p. 175.
- Kruuk LEB. 2004. Estimating genetic parameters in natural populations using the 'animal model'. *Philosophical Transactions of the Royal Society B, London*, **359** (1446): 873-890. DOI: <https://doi.org/10.1098/rstb.2003.1437>.
- Mrode RA. 2005. Linear models for the prediction of animal breeding values (2<sup>nd</sup> edn). CABI Publishing: Cambridge, MA 02139, USA; p. 344.
- Patterson HD, Thompson R. 1971. Recovery of Inter-Block Information when Block Sizes are Unequal. *Biometrika*, **58**: 545 - 554. DOI: <https://doi.org/10.2307/2334389>

- Plazas M, Vilanova S, Gramazio P, Rodriguez-Burruezo A, Fita A, Herraiz FJ, Ranil R, Fonseka R, Niran L, Fonseka H, Kouassi B, Kouassi AB, Kouassi A, Prohens J. 2016. Interspecific hybridization between eggplant and wild relatives from different gene pools. *Journal of the American Society for Horticultural Science*, **141** (1): 34-44. DOI: <https://doi.org/10.21273/jashs.141.1.34>
- Prohens J, Plazas M, Raigón MD, Seguí-Simarro JM, Stommel JR, Vilanova S. 2012. Characterization of interspecific hybrids and first backcross generations from crosses between two cultivated eggplants (*Solanum melongena* and *S. aethiopicum* Kumba group) and implications for eggplant breeding. *Euphytica*, **186** (2): 517-538. DOI: <https://doi.org/10.1007/s10681-012-0652-x>
- Ranil RHG, Prohens J, Aubriot X, Niran HML, Plazas M, Fonseka RM, Vilanova S, Fonseka HH, Gramazio P, Knapp S. 2017. *Solanum insanum* L. (subgenus *Leptostemonum* Bitter, Solanaceae), the neglected wild progenitor of eggplant (*S. melongena* L.): a review of taxonomy, characteristics and uses aimed at its enhancement for improved eggplant breeding. *Genetic Resources and Crop Evolution*, **64** (7): 1707 - 1722. DOI: <https://doi.org/10.1007/s10722-016-0467-z>
- Sawadogo B, Bationo-Kando P, Sawadogo N, Kiebre Z, Kiebre M, Nanema KR, Traore RE, Sawadogo M, Zongo JD. 2016. Variation, Correlation and heritability of interest characters for selection of African eggplant. *African Crop Science Journal*, **24** (2) : 213 – 221. DOI: <http://dx.doi.org/10.4314/acsj.v24i2.9>.
- Sumathi P, Sumanth M, Veerabhadhiran P. 2010. Genetic variability for different biometrical traits in Pearl Millet genotypes (*Pennisetum glaucum* LR BR.). *Electronic Journal of Plant Breeding*, **1** (4): 437 - 440.
- Toudou DAK, Atta S, Inoussa MM, Bakasso Y. 2017. Mécanisme de tolérance à la sécheresse du niébé pendant la phase végétative. *Journal of Applied Biosciences*, **117**: 11737-11743. DOI: <https://dx.doi.org/10.4314/jab.v117i1.10>.
- UBI W, UBI MW, IBOR O, AKPANIDIOK AU.2014. Seasonal variations in the growth duration of some rice varieties grown in cross river state. *Global Journal of Agricultural Sciences*, **13**: 1 – 6. DOI: <http://dx.doi.org/10.4314/gjass.v13i1.1>.
- Vorontsova MS, Knapp S. 2016. A revision of the “spiny solanums”, *Solanum* subgenus *Leptostemonum* (Solanaceae) in Africa and Madagascar. *Systematic Botany Monographs*, **99**: 1 - 436. DOI: <https://doi.org/10.5519/0055154>.