Maize (*Zea mays* L.) from the Saharan oasis: adaptation to temperate areas and agronomic performance

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Abstract

Saharan maize had been adapted to extreme conditions and could have developed resistance to different stresses. However, genebanks and breeding collections have poor representation from Saharan germplasm and, particularly, from Algeria. This is a preliminary approach to investigate the adaptation and agronomic performance of a representative sample of Saharan maize. We evaluated open-pollinated Saharan populations along with European and American cultivars during two years in humid and dry Spanish locations and in Algiers (Algeria). Saharan populations were able to grow in temperate environments, although results were not consistent over years and the genotype-by- environment interactions were very important. Some of the Algerian populations evaluated in 2010 showed promising yield and anthesis – silking interval over environments, but none of the Algerian populations evaluated in 2009 were adequately adapted to Spanish conditions. These results suggest that there are wide ranges of variability within Saharan maize for adaptation to temperate conditions, and further evaluations of Saharan maize should identify potential base populations for breeding maize in either side of the Mediterranean Sea. However, this germplasm requires prebreeding for adaptation to temperate conditions in order to be adequate for breeding programs in temperate areas.

Keywords: adaptation, germplasm, stress *Zea mays* L.

Introduction

The Sahara desert has a dry subtropical climate characterized by annually high temperature ranges, cold winters, hot summers and two rainy seasons. The vegetation found in the Sahara must be adapted to unreliable precipitation and excessive heat. Interestingly enough, maize has been cultivated in oasis for several centuries and now is at risk of extinction. During several centuries, that germplasm had been adapted to extreme conditions and could have developed resistance to a cultivar of biotic or abiotic stresses.

During the last half of the XXth Century, the Corn Belt hybrids were distributed throughout the World, putting in risk the conservation of the autochthonous cultivars everywhere. Moreover, traditional farms and their cultivars are being abandoned as they become less competitive compared to modern intensive agriculture. One of the scientific priorities is to collect, preserve, and valorize biodiversity before extinction for further use of these material in the future breeding program as source of adaptation to extreme conditions. Actually, autochthonous maize germplasm from the African side of the Mediterranean area is poorly represented in genebanks and breeding collections, although there are some recent initiatives for conserving maize genetic resources from several countries, including Egypt (Wale 2008).

There are few imprecise historical records of maize introduction in Africa. Grigg (1974) affirms that maize was introduced by the Turks in Egypt soon after the invasion in 1517, and According to Hafnagel (1961); maize was introduced in Ethiopia by the seventeenth century. A few genetic studies of variability in African maize have been reported by Sanou et al. (1997) and Beyene et al. (2006) showing that the variability available in those African countries is large and can be the basis of breeding programs. Accordingly, Badu-Apraku et al. (2007) reported a wide range of diverse efforts for increasing sustainable production of maize in sub-

Saharan Africa. Contrarily, there are no published reports concerning genetic diversity of maize germplasm in the Sahara desert or even in most North African countries. Saharan maize has evolved from tropical introductions made by Spanish muslin pilgrims during the XVIth Century or from subsequent reintroductions by Turkish or French conquerors (Revilla et al. 1998; Sanou et al. 1997; Weatherwax and Randolph 1955). Algeria is the country with the largest portion of Sahara desert. Recently, maize germplam has been collected in the Algerian oasis, and that collection is being studied nowadays. The remains of uncertain origin grown in the oasis of the Sahara desert could constitute a unique germplasm pool because of its history and its potential value as sources of alleles for tolerance to biotic or abiotic stress.

Besides collecting and conserving the Saharan maize germplasm, there are a number of interesting question to investigate, such as the diversity available, the origin of the germplasm or its potential value for breeding. In this first work, we adopt a breeding perspective and investigate the adaptation and agronomic performance of a representative sample of Saharan maize in temperate areas.

Materials and methods

A collection of maize populations from the Algerian Sahara is conserved in the National School of Agronomy of Algiers. From that collection, a sample has been evaluated for adaptation and agronomic performance in three distinct environments (Table 1). Saharan sample consisted on 10 open-pollinated population's representative of the maize grown in the Saharan oasis. These populations were assayed along with 13 cultivars from the dry Spain, four cultivars from the humid Spain, four cultivars and three single crosses from the US Corn Belt, and three crosses among cultivars from these temperate origins. The trials were carried out in 2009 and 2010 in Pontevedra, Saragossa and Algiers. Pontevedra (42° 24', 8' 38'N, altitude 20 m) is in the humid Spain; Saragossa (41º 41' N, 0º 49' W, altitude 250 m) is in the dry Spain; and Algiers (36 º 47 ' N, 2 º 03' E, altitude 32 m) is in the sub humid North of Algeria.

The cultivars were evaluated in randomized complete block designs with three replications. Each experimental plot consisted of two rows with 25 hills per row and one grain per hill. Rows were spaced 0.80 m apart and hills were spaced 0.18 m achieving a final plant density of approximately 69000 plants ha^{-1}. Currently accepted management and cultural practices were used in all trials including frequent irrigation at Saragossa, less frequent irrigation at Algiers, and no irrigation at Pontevedra. We measured 17 traits related to adaptation and agronomic behavior (Table 2).

Given the limited seed availability from the Algerian populations, they were not evaluated in Algiers in 2009. Due to the poor performance of many of the first set of populations evaluated in 2009 and the limited seed availability of the Algerian populations, we chose a different set of cultivars for 2010, except for three common checks that were repeated in all environments. Therefore, the cultivars evaluated in each environment were not the same except for three cultivars that were repeated in all environments in order to be used as common references: EPS13(FR)C3, EPS14(FR)C3, and BS17C5, from humid and dry Spain and from the US Corn Belt, respectively. In order to compare the cultivars across environments, for each trait, means were corrected for year effect and for location effect by using the deviation of means of common cultivars in single locations and years from the overall mean as follows:

$$Mvyl = \Sigma\,[Mi + (My - Mt) + (Ml - My')]$$

Where:

Mvyl is the mean of each cultivar (v) corrected by year (y) and location (l) effects

Mi is the raw mean of each cultivar in the l location and y year

My is the mean of the three common cultivars in y year

Mt is the mean of the three common cultivars across years

Ml is the mean for the cultivars evaluated in the l location

My' is the mean of the common cultivars across locations

The relationships among environments were estimated by means of Pearson correlation analyses between each pair of locations (Pontevedra, Saragossa and Algiers) for six traits presumably affected by environment: Stand, male and female flowering, anthesis – silking interval, grain yield and moisture. Analyses of variance were performed for each trait, being the sources of variation locations, years, cultivars, repetitions and their interactions. Cultivars and locations were considered fixed effects, while years and interactions with random factors were considered random effects. Comparisons of means were performed for each trait using Fisher's protected least significant difference (LSD) and the standard error of difference (SED) at $P = 0.05$ (Steel et al. 1997). LSD and SED for each comparison were calculated from the analysis of variance of the common populations for the corresponding environments or group of cultivars. Analyses were made using GLM procedure of SAS (SAS Institute 2005).

Results and discussion

The individual analyses of variance for each environment showed significant differences among cultivars for all traits except for Algiers in 2010, wherein differences were not significant for stand, flowering dates, anthesis – silking interval (ASI), and grain moisture (data not shown). Combined-over-locations analyses of variance in 2009 and 2010 revealed significant genotype-by- environment interactions (GE) for most traits. Noteworthy, interactions were always significant for early vigor, yield and moisture. GE was significant for all traits except plant height in 2009, while in 2010 they were only significant for half of the traits, including yield and moisture. Significant GE was often of rank rather than of magnitude. This high frequency of significant effects and interactions is normal for such a wide range of diversity in populations and environments (Revilla et al. 2006; Romay et al. 2010). We can conclude from these analyses that adaptation and agronomic performance of these genotypes should be restricted to each specific environment. These analyses of variance are consistent with the wide climatic adaptation range of the genotypes, as stated by Ruiz Corral et al. (2008) for a collection of Mexican landraces.

Diversity among environments were studied through correlation analyses of the performance of each cultivar in each environment for six traits associated to maize adaptation, namely stand, male and female flowering, ASI, yield and grain moisture (Table 3). Female and male flowering were consistent across environments based on the reasonably high correlations between environments for these traits. Considering all traits together, correlations were highest between Pontevedra (humid Spain) and Algiers (sub humid Northern Africa) for male (0.93) and female (0.91) flowering and ASI (0.55), and between Pontevedra and Saragossa (dry Spain) for yield (0.84). Similarities and dissimilarities could be explained because weather conditions of Pontevedra (humid and mild temperature) were more similar to those of Algiers (sub humid and mild temperature) than of Saragossa (dry and continental). Contrarily, high correlation between Pontevedra and Saragossa for yield can be due to similar agronomical practices because both research institutes have long tradition growing maize, while maize is a new crop in the Algerian field. On the other hand, moisture data in Pontevedra was not correlated with the other two locations because Pontevedra has high relative humidity at harvest, as well as twice the rainfall of Algiers and four times the rainfall of Saragossa. Our results show that these three environments are clearly diverse and most of the evaluated populations were able to grow and produce grain in most environments, which would allow using these populations as potential sources of favorable genes for diverse uses. Evaluations in diverse environments allow plant breeders either the identification of specifically adapted cultivars for each environment (Gomes et al. 2000; Abera et al. 2004; Setimela et al. 2007) or with wide ranges of adaptation and specific aptitudes of cultivars for diverse environments (Gomes et al. 2000; Setimela et al. 2007).

The main purpose of this research is evaluating adaptation of the Saharan maize to temperate conditions. Even though significant GE requires appropriate analyses by environments, we can draw some general conclusions from means across environments (Table 4). The five Saharan populations evaluated in all locations in 2010 had a reasonably good germination while the five evaluated in 2009 had poor germination (<50%) in the Spanish locations. Low germination could be due to poor seed conservation; therefore, seed viability should be urgently checked and the seed renewed for the samples with poorer performance. After emergence, Algerian populations were able to grow without any problem, actually their early vigor was between 4 and 5.9; being three of them significantly more vigorous than the weakest maize populations from Spain or the USA. Similarly, stand was normal or even high for the Algerian populations.

Considering that these populations come from a semitropical area (< 30º N), we could expect some problems with flowering and grain production. Although we have no data concerning the flowering time in their original growing area, seed providers informed that their growing season is short. In temperate locations, these populations had medium growth cycle with a female flowering between 67 and 84 days, a male flowering between 68 and 89 and a normal ASI (around 2 days) (Table 4). Therefore, we can assume that there were no major constraints for growing these populations under temperate conditions, even if their cycle was delayed. Although half of the shortest populations were from Algeria, plant growth was normal, with plant height between 127 and 188 cm and ear height between 35 and 112 cm.

The major handicap for using these populations under temperate conditions is their poor ability for seed production. Actually, the adjusted yields reported in Table 5 are not significantly different from 0 for all the Algerian populations grown in Spain in 2009. Even though all cultivars produced some grain, when the figures were adjusted by year and location effects, the results were close to zero. Contrarily, the yield of the Algerian populations grown in 2010 was not significantly different from most of the temperate populations. Nevertheless, the Algerian populations had values of kernel weight and grain moisture similar or below those shown by temperate populations. Furthermore, the values of prolificacy for most Algerian populations are above those of the temperate populations and hybrids. The agronomic values of these Saharan populations were within the range of most autochthonous populations (Revilla et al. 2006; Romay et al. 2010).

Given that the GE interaction was often of rank, we have to pay attention to adaptation for each environment (Table 6). The GE for yield was so important that the highest yielder in Saragossa was the classical hybrid B73 x Mo17, that was surpassed by other hybrids and even some inbred x population crosses in Pontevedra, while in Algiers the highest yield corresponded to some populations. In

2009, the Algerian populations were not evaluated in Algiers due to limited seed availability, but they had a very low yield and their ranks for yield were very similar between both Spanish locations. The rank variations between Pontevedra and Saragossa were more frequent for female flowering, particularly for the Algerian population DZTAD that was earlier in Saragossa than in Pontevedra. GE was more important for ASI, which was larger in Saragossa due to the drier and warmer conditions compared to Pontevedra. The rank of the Algerian populations for ASI was shorter in Pontevedra than in Saragossa. Grain moisture was obviously highest in Pontevedra and variations between Pontevedra and Saragossa were also large. However, such variations were not very important for the Algerian populations.

In 2010, GE was significant for yield and grain moisture and interactions were of rank, rather than of magnitude (Table 6). As hybrids were not included in the trials of 2010, the highest yielders were the improved synthetic EPS14(FR)C3 from dry Spain in Algiers, the local population from southern Spain Basto in Pontevedra, and the improved Corn Belt synthetic BS17C5 in Saragossa. The strong GE was shown by EPS14(FR)C3 that was seventh for yield in Pontevedra, Basto that was ninth in Algiers, and by BS17C5 that was fifth in Pontevedra. Conversely, the lowest part of the rank for yield corresponded to the Algerian population BZBSA in all locations. Nevertheless, the GE affected similarly the Algerian populations; e.g., concerning moisture, the trial of Algiers had the largest number of discrepancies, affecting particularly the Algerian populations; the most extreme interaction was for DZBSA that had the third moisture in Algiers and the ninth and tenth in Pontevedra and Saragossa, respectively. GE was not significant for flowering or ASI in 2010, and actually some populations had some consistent positions in the ranks of the three locations, particularly DZBTM was the fourth in the rank of late populations, while and DZBSA was the earliest population in all locations. Finally, the rank for ASI was consistent for most populations. However, there were also important rank variations for ASI, particularly for BS17C5 that had the largest value in Pontevedra and was sixth in Algiers and Saragossa, or for DZAAS that had the shortest ASI in Saragossa and one of the largest in Algiers, although these values were not significantly different.

As conclusions, adaptation of Saharan populations to temperate environments was sound, although environmental effects between years could be the main limiting factor. This is in agreement with previous reports showing that climatic limits of maize are wide, indicating that maize has evolved to great adaptability and great expansion its geographic range (Ruiz Corral et al. 2008). However, the tropical populations evaluated by Ruiz Corral et al. (2008) were adequately adapted solely within the limits of tropical environments and differences in adaptation depended on genotypes. Therefore, we can search genes for adaptive features (e.g. severe temperature tolerance) which, according to Hawtin et al. (1996), may be found in extreme environments, or to other purposes (e.g. photoperiod insensitivity) that may have evolved away from primary centers of origin. Indeed, we could also expect that semitropical maize will need selection for tolerance to temperate conditions in order to be adequate for breeding programs in temperate areas (Soldati et al. 1999).

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Table 1. Maize cultivars from four diverse origins evaluated in Pontevedra, Saragossa and Algiers in 2009 and 2010

Cultivar	Type of germplasm	Evaluation
Saharan oasis		
DZAAS	Autochthonous population	2010
DZBAB	Autochthonous population	2010
DZBSA	Autochthonous population	2010
DZBTM	Autochthonous population	2010
DZSHH	Autochthonous population	2010
KAAAAd	Autochthonous population	2009
KHGTAd	Autochthonous population	2009
MHAd	Autochthonous population	2009
RGNAd	Autochthonous population	2009
ZDTAd	Autochthonous population	2009
Dry Spain		
Basto	Autochthonous population	2010
Borja	Autochthonous population	2009
Castellote	Autochthonous population	2009
Castelseras	Autochthonous population	2009
Fino	Autochthonous population	2009
Hembrilla/Queixalet	Autochthonous population	2009
La Codoñera	Autochthonous population	2009
Moya	Autochthonous population	2009
Rastrojero	Autochthonous population	2009
Villanueva del Arzobispo	Autochthonous population	2009

EPS12(T)C5	Improved composite	2009
EPS14(FR)C3	Improved composite	Both
EZS33C3	Improved composite	2009
Humid Spain		
Soraluze	Autochthonous population	2009
Rebordanes(S)C2	Improved autoch. population	2009
Tuy(S)C3	Improved autoch. population	2009
EPS13(FR)C3	Improved composite	Both
US Corn Belt		
Minnesota13	Autochthonous population	2010
EZS34C3	Improved composite	2009
BS17C5	Improved composite	Both
BSP1C4	Improved composite	2009
A619xA632	Single hybrid	2009
B73xMo17	Single hybrid	2009
C123xB14A	Single hybrid	2009
Miscellaneous		
EPS13(FR)C3xEPS14(FR)C3	Improved composites	2009
B93xEPS14(FR)C3	Inbred x Improved composite	2009
B93xEPS13(FR)C3	Inbred x Improved composite	2009

Table 2. Traits measured in the evaluation of maize cultivars from four diverse origins in Pontevedra, Saragossa and Algiers in 2009 and 2010

Trait	Definition	Units
Proportion of emergence	% plants emerged from grains sowed	%
Early vigor	Scale 1-9: 1=weak to 9=vigorous	1 – 9
Stand	% plants that reached the adult stage	%
Stem lodging	% plants broken below the main ear	%
Root lodging	% plants lying more than 30º from vertical	%
Days to silking	From planting to 50% plants silking	Days
Days to anthesis	From planting to 50% plants with anthers	Days
Anthesis – silking interval	Scale 1-9: 1=weak to 9=vigorous	1 – 9
Plant height	From the soil to the top of the tassel	cm
Ear height	From the soil to the ear-insertion node	cm
Ears per plant	Ears per plot / Plants per plot	No.
Grain moisture	Moisture content at harvest	g kg^{-1}
Grain yield	Weight of grain per hectare at 140 g kg^{-1} moisture	Mg ha^{-1}
Ear appearance	Scale 1-9: 1=poor to 9=good	1 – 9
Ear length	From bottom to top ear, 10 ears/plot	cm
100 grain weight	100 grains from the center of the ears	g
Ear rows	Number of grain rows (10 ears)	No.

Table 3. Pearson’s correlations between environments for 6 common traits

		Algiers	Dry Spain
Stand	Humid Spain	0.03	-0.51
	Dry Spain	-0.03	
Male flowering	Humid Spain	0.93	0.67
	Dry Spain	0.71	
Female flowering	Humid Spain	0.91	0.67
	Dry Spain	0.51	
ASI	Humid Spain	0.55	0.31
	Dry Spain	0.04	
Yield	Humid Spain	0.65	0.84
	Dry Spain	0.44	
Moisture	Humid Spain	0.04	0.29
	Dry Spain	0.41	

Table 4. Adjusted[a] means of vegetative traits from the evaluation of maize cultivars from four diverse origins in Pontevedra (humid Spain, DSP), Saragossa (dry Spain, HSP) and Algiers (ALG) in 2009 and 2010.

Origin	Cultivar	Evaluation		Emergence	Early vigor	Stand	Female flowering	Male flowering	Anthesis-Silking interval	Plant height	Ear height
		Year	Location	%	1 - 9	%	Days	days	days	cm	cm
ALG	DZAAS	2010	All	72	5.9	96	71.5	73.6	2.13	146.5	57.8
ALG	DZBAB	2010	All	62	4.7	79	78.9	80.6	1.80	161.6	71.4
ALG	DZBSA	2010	All	65	5.9	60	67.6	68.6	1.02	127.3	35.7
ALG	DZBTM	2010	All	69	4.9	77	77.0	78.6	1.69	166.9	69.1
ALG	DZSHH	2010	All	70	5.6	81	74.3	75.3	1.02	154.0	64.7
ALG	KAAAAd	2009	HSP-DSP	21	4.8	64	73.8	75.2	1.44	173.7	109.7
ALG	KHGTAd	2009	HSP-DSP	8	5.3	57	84.3	88.9	4.61	188.5	110.1

ALG	MHAd	2009	HSP-DSP	23	5.2	100	73.0	75.2	2.27	177.0	111.0
ALG	RGNAd	2009	HSP-DSP	18	4.0	75	74.3	76.4	2.11	157.3	96.5
ALG	ZDTAd	2009	HSP-DSP	42	5.3	67	77.0	79.2	2.27	182.9	111.9
DSP	Basto	2010	All	59	5.7	85	79.3	81.2	1.91	187.0	86.0
DSP	Borja	2009	All	69	6.0	87	68.7	72.2	3.54	162.9	90.7
DSP	Castellote	2009	All	59	5.8	88	76.7	79.4	2.65	209.4	121.4
DSP	Castelseras	2009	All	63	3.8	89	92.3	94.7	2.43	140.0	102.7
DSP	Fino	2009	All	75	6.5	93	75.3	79.1	3.87	213.3	134.2
DSP	Hembrilla/Queixalet	2009	All	78	5.5	88	74.4	76.6	2.20	184.6	113.5
DSP	La Codoñera	2009	All	57	4.0	87	92.3	95.4	3.09	141.0	102.2
DSP	Moya	2009	All	37	4.8	75	75.3	76.8	1.54	180.8	105.9
DSP	Rastrojero	2009	All	65	5.7	91	74.6	78.0	3.43	172.8	101.0
DSP	Villanueva Arzobispo	2009	All	65	5.0	85	81.9	85.0	3.09	209.3	162.2
DSP	EPS12(T)C5	2009	All	65	5.2	77	66.0	70.6	4.54	131.1	41.9

DSP	EPS14(FR)C3	Both	All	78	6.9	86	70.8	73.3	2.56	176.2	72.1
HSP	EZS33C3	2009	All	80	5.2	85	75.4	80.1	4.76	179.6	111.4
HSP	Soraluze	2009	All	67	6.5	86	70.6	74.2	3.65	190.5	84.0
HSP	Rebordanes(S)C2	2009	All	83	8.2	86	72.4	75.8	3.43	180.5	103.2
HSP	Tuy(S)C3	2009	All	83	8.5	84	70.0	72.9	2.87	186.7	99.9
HSP	EPS13(FR)C3	Both	All	77	7.6	84	70.2	74.2	4.06	177.6	78.6
USA	Minnesota13	2010	All	72	7.3	89	71.0	73.8	2.80	184.8	68.2
USA	EZS34C3	2009	All	77	5.3	84	79.9	82.4	2.43	196.5	90.9
USA	BS17C5	Both	All	73	6.7	89	78.7	81.3	2.56	192.3	93.3
USA	BSP1C4	2009	All	83	3.8	90	78.4	80.9	2.54	183.1	111.4
USA	A619xA632	2009	All	83	6.7	89	77.8	79.6	1.76	234.1	109.5
USA	B73xMo17	2009	All	36	5.5	68	83.4	84.0	0.65	218.3	125.4
USA	C123xB14A	2009	All	68	6.2	92	80.8	83.7	2.87	217.1	111.8
HSP x DSP	EPS13C3xEPS14C3	2009	All	92	7.2	80	68.7	72.6	3.87	197.6	95.7

USA x DSP	B93xEPS14C3	2009	All	83	7.5	85	74.1	75.8	1.65	207.4	101.0
USA x HSP	B93xEPS13C3	2009	All	86	7.2	71	73.7	76.0	2.31	202.7	93.0
LSD (0.05) SED (0.05)	Total			14 5.60	1.6 0.71	7 3.0	2.0 0.91	2.1 0.93	1.22 0.55	17.8 7.27	18.7 6.73
	2009, HSP-DSP				1.6 0.78	57 27.8	6.1 2.96	5.7 2.78	1.98 0.96		
	2009 (excluding ALG)				1.5 0.72	24 11.8	4.1 2.04	4.1 2.04	2.18 1.08	19.7 9.54	
	2010			11 5.3	2.2 1.04	18 8.40	3.1 1.87	3.3 1.55	1.39 0.66	19.1 9.11	

[a] Means were adjusted by location and year effects as explained in Materials and Methods

Table 5. Adjusted[a] means of ear traits from the evaluation of maize cultivars from four diverse origins in Pontevedra (humid Spain, HSP), Saragossa (dry Spain, DSP) and Algiers (ALG) in 2009 and 2010.

Origin	Cultivar	Evaluation		Grain yield	Grain moist.	Kernel weight	Ears / plant
		Year	Location	Mg ha^{-1}	g kg^{-1}	100 x g	N.
ALG	DZAAS	2010	All	5.01	12.3	29.1	1.36
ALG	DZBAB	2010	All	4.38	17.6	21.4	1.64
ALG	DZBSA	2010	All	2.13	12.3	18.9	1.01
ALG	DZBTM	2010	All	3.94	14.2	25.1	1.31
ALG	DZSHH	2010	All	3.99	14.1	22.4	1.44
ALG	KAAAAd	2009	H-DSP	0.00[b]	16.5	22.9	1.68
ALG	KHGTAd	2009	H-DSP	0.00[b]	19.3	37.6	1.67
ALG	MHAd	2009	H-DSP	0.60	16.1	21.9	1.30
ALG	RGNAd	2009	H-DSP	0.00[b]	16.1	19.9	1.67
ALG	ZDTAd	2009	H-DSP	1.17	16.7	22.9	1.62
DSP	Basto	2010	All	4.98	19.6	36.1	0.90
DSP	Borja	2009	All	2.98	16.0	13.6	1.24
DSP	Castellote	2009	All	6.54	18.1	37.3	1.02
DSP	Castelseras	2009	All	1.93	19.0	11.6	1.17

DSP	Fino	2009	All	5.59	17.6	22.6	1.21
DSP	Hembrilla/Queixalet	2009	All	5.05	16.4	24.3	1.07
DSP	La Codoñera	2009	All	2.20	17.9	11.9	1.14
DSP	Moya	2009	All	2.41	15.8	28.6	1.14
DSP	Rastrojero	2009	All	4.27	16.3	31.9	0.97
DSP	Villanueva Arzobispo	2009	All	3.77	16.7	17.3	1.33
DSP	EPS12(T)C5	2009	All	1.56	16.3	23.3	0.91
DSP	EPS14(FR)C3	Both	All	4.65	16.0	33.0	1.13
HSP	EZS33C3	2009	All	6.11	17.7	31.9	1.04
HSP	Soraluze	2009	All	5.25	16.0	27.9	1.03
HSP	Rebordanes(S)C2	2009	All	5.27	17.3	29.6	1.08
HSP	Tuy(S)C3	2009	All	5.05	16.6	31.9	1.07
HSP	EPS13(FR)C3	Both	All	4.14	15.1	29.8	1.04
USA	Minnesota13	2010	All	4.23	13.9	25.4	0.90
USA	EZS34C3	2009	All	8.09	18.2	27.9	1.00
USA	BS17C5	Both	All	5.86	17.2	27.3	0.94
USA	BSP1C4	2009	All	3.62	14.5	9.9	1.20
USA	A619xA632	2009	All	9.15	17.4	31.9	0.99
USA	B73xMo17	2009	All	7.40	19.3	31.6	1.02
USA	C123xB14A	2009	All	9.31	17.3	31.9	0.99
HSP x DSP	EPS13C3xEPS14C3	2009	All	6.29	17.2	31.3	1.03
USA x DSP	B93xEPS14C3	2009	All	8.33	17.8	33.9	1.01
USA x HSP	B93xEPS13C3	2009	All	7.67	18.1	33.6	1.07
LSD (0.05)				1.13	1.8	11.2	0.14
	Total			0.50	0.79	2.60	0.06
	2009, HSP-DSP			2.98	2.0		0.32

SED (0.05)				1.45	1.04		0.15
	2009 (excluding ALG)			3.07 1.53			0.20 0.09
	2010			1.54 0.73	3.8 1.97		0.34 0.16

[a] Means were adjusted by location and year effects as explained in Materials and Methods

[b] This value was obtained after correcting the raw data for location and year effect, although these cultivars produced actually some grain

Table 6. Adjusted[1] means per location and year of four traits related to adaptation from the evaluation of maize cultivars from four diverse origins in Pontevedra (humid Spain, HSP), Saragossa (dry Spain, DSP) and Algiers (ALG) in 2009 and 2010.

	ALG	HSP	DSP	ALG	HSP	DSP	ALG	HSP	DSP	ALG	HSP	DSP
Cultivar	Female flowering (days)			Anthesis - silking interval (days)			Yield (Mg g^{-1})			Grain moisture (g kg^{-1})		
Year 2009												
A619xA632	81	83	76	6.0	0.0	0.7	4.36	15.38	9.52	14.0	18.7	14.2
B73xMo17	82	92	79	2.3	-1.0	2.0	1.41	10.93	11.66	17.2	21.3	14.2
B93xEPS13(FR)C3	75	81	72	3.7	1.0	1.7	4.48	14.16	8.23	13.3	20.8	14.2
B93xEPS14(FR)C3	75	81	72	4.7	2.0	1.7	3.28	13.21	8.33	12.7	21.3	15.2
Borja	71	78	68	5.3	2.3	4.3	2.65	4.95	3.16	11.3	17.8	13.9
BS17C5	80	88	78	5.0	1.3	2.3	4.72	10.08	6.98	10.0	19.1	15.0
BSP1C4	79	86	78	6.0	0.7	2.3	3.57	6.21	2.90	9.3	15.8	13.2
C123xB14A	84	91	77	5.0	1.7	3.3	5.81	13.83	10.10	12.0	20.4	14.3

Castellote	80	85	74	5.3	1.3	2.7	4.16	9.91	7.37	14.0	20.2	14.9
Castelseras	90	105	90	2.7	2.0	4.0	1.85	2.53	3.22	14.0	23.9	14.2
EPS12(T)C5	73	76	63	10.3	2.3	2.3	2.36	2.74	1.39	11.3	19.1	13.4
EPS13(FR)C3	75	78	69	9.0	1.7	3.3	1.90	7.18	4.24	11.3	18.2	13.5
EPS13(FR)C3xEPS14(FR)C3	71	79	68	7.3	2.0	3.7	4.47	9.94	6.29	13.3	19.6	13.7
EPS14(FR)C3	72	78	68	6.3	-1.0	3.7	3.10	6.57	4.62	10.0	18.5	13.9
EZS33C3	79	84	77	10.0	2.3	3.3	4.74	8.92	6.48	12.0	20.3	15.7
EZS34C3	80	89	79	5.0	1.3	2.3	5.74	11.27	9.09	14.7	20.4	14.6
Fino	79	85	75	7.7	2.0	3.3	5.02	8.78	4.79	13.3	20.2	14.1
Hembrilla/Queixalet	74	84	73	4.0	1.0	3.0	4.01	7.33	5.63	10.7	19.1	14.2
KAAAAd		79	74		-0.3	1.7		2.36	0.97		19.3	13.4
KHGTAd		93	87		1.3	6.3		1.06	0.81		22.3	15.9
La Codoñera	90	105	92	3.3	2.3	5.0	3.30	2.44	2.69	13.3	19.7	15.7
MHAd		80	72		0.3	2.7		2.98	1.73		18.2	13.7

Moya	75	85	72	4.3	-0.3	2.0	2.12	3.45	3.49	9.7	18.9	13.7
Rastrojero	75	86	73	5.7	2.0	4.0	3.79	5.85	4.98	11.7	18.4	13.7
Rebordanes(S)C2	76	80	72	8.3	1.7	1.7	4.33	8.83	4.45	14.7	18.5	13.5
RGNAd		80	75		-0.7	3.3		2.11	0.75		18.4	13.5
Soraluze	71	75	77	7.0	2.7	2.7	2.57	5.82	9.18	8.3	18.5	16.2
Tuy(S)C3	75	75	70	5.7	2.0	2.3	3.74	8.81	4.41	12.3	19.1	13.3
Villanueva del Arzobispo	82	95	79	5.7	1.3	3.7	2.83	5.89	4.43	11.3	19.0	14.6
ZDTAd		82	79		-0.7	3.7		4.12	1.73		19.3	13.7
LSD (0.05) SED (0.05)	3.8 1.89	3.6 1.81	2.5 1.24	2.83 1.40	2.35 1.18	1.97 0.98	1.36 0.67	3.38 1.69	0.53 0.26	3.7 1.85	1.7 0.86	0.9 0.43
Year 2010												
Basto	76	82	84	1.7	-0.7	3.3	1.56	6.67	4.89	14.9	23.5	25.4
BS17C5	72	85	84	2.0	2.0	2.7	2.94	4.73	5.69	15.9	21.0	22.2
DZAAS	71	74	75	3.0	0.7	1.3	3.09	5.71	4.40	15.2	13.2	13.6

DZBAB	75	82	85	2.3	-1.0	2.7	2.44	4.68	4.21	15.6	20.7	21.5
DZBSA	66	70	69	1.3	-2.0	2.3	1.53	0.81	2.24	15.3	13.8	12.8
DZBTM	71	82	82	1.7	-0.7	2.7	2.00	4.86	3.15	15.2	16.0	16.5
DZSHH	68	77	80	1.7	-2.0	2.0	2.52	3.22	4.42	14.7	15.2	17.5
EPS13(FR)C3	70	76	76	3.7	2.0	4.7	2.67	3.95	4.89	14.5	16.6	16.6
EPS14(FR)C3	68	77	76	2.3	1.0	3.0	4.03	4.42	5.18	15.0	20.3	18.1
Minnesota13	69	74	77	2.7	1.3	3.0	2.29	4.80	3.79	14.6	14.4	17.6
LSD (0.05)	7.0	3.0	1.4	3.90	1.49	1.16	1.24	2.08	0.92	1.4	2.1	4.8
SED (0.05)	3.48	1.44	0.65	1.85	0.71	0.55	0.58	0.99	0.43	0.65	1.01	2.27