1	Maize (Zea mays L.) from the Saharan oasis: adaptation to temperate areas and
2	agronomic performance
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21 Abstract

22	Saharan maize had been adapted to extreme conditions and could have developed
23	resistance to different stresses. However, genebanks and breeding collections have
24	poor representation from Saharan germplasm and, particularly, from Algeria. This is
25	a preliminary approach to investigate the adaptation and agronomic performance of
26	a representative sample of Saharan maize. We evaluated open-pollinated Saharan
27	populations along with European and American cultivars during two years in humid
28	and dry Spanish locations and in Algiers (Algeria). Saharan populations were able to
29	grow in temperate environments, although results were not consistent over years and
30	the genotype-by- environment interactions were very important. Some of the
31	Algerian populations evaluated in 2010 showed promising yield and anthesis -
32	silking interval over environments, but none of the Algerian populations evaluated
33	in 2009 were adequately adapted to Spanish conditions. These results suggest that
34	there are wide ranges of variability within Saharan maize for adaptation to temperate
35	conditions, and further evaluations of Saharan maize should identify potential base
36	populations for breeding maize in either side of the Mediterranean Sea. However,
37	this germplasm requires prebreeding for adaptation to temperate conditions in order
38	to be adequate for breeding programs in temperate areas.
39	
40	Keywords: adaptation, germplasm, stress Zea mays L.

43 Introduction

44 The Sahara desert has a dry subtropical climate characterized by annually 45 high temperature ranges, cold winters, hot summers and two rainy seasons. The 46 vegetation found in the Sahara must be adapted to unreliable precipitation and 47 excessive heat. Interestingly enough, maize has been cultivated in oasis for several 48 centuries and now is at risk of extinction. During several centuries, that germplasm 49 had been adapted to extreme conditions and could have developed resistance to a 50 cultivar of biotic or abiotic stresses. During the last half of the XXth Century, the Corn Belt hybrids were 51 52 distributed throughout the World, putting in risk the conservation of the 53 autochthonous cultivars everywhere. Moreover, traditional farms and their cultivars 54 are being abandoned as they become less competitive compared to modern intensive 55 agriculture. One of the scientific priorities is to collect, preserve, and valorize 56 biodiversity before extinction for further use of these material in the future breeding 57 program as source of adaptation to extreme conditions. Actually, autochthonous 58 maize germplasm from the African side of the Mediterranean area is poorly 59 represented in genebanks and breeding collections, although there are some recent 60 initiatives for conserving maize genetic resources from several countries, including 61 Egypt (Wale 2008). 62 There are few imprecise historical records of maize introduction in Africa. 63 Grigg (1974) affirms that maize was introduced by the Turks in Egypt soon after the 64 invasion in 1517, and According to Hafnagel (1961); maize was introduced in 65 Ethiopia by the seventeenth century. A few genetic studies of variability in African 66 maize have been reported by Sanou et al. (1997) and Beyene et al. (2006) showing 67 that the variability available in those African countries is large and can be the basis 68 of breeding programs. Accordingly, Badu-Apraku et al. (2007) reported a wide 69 range of diverse efforts for increasing sustainable production of maize in sub-

70 Saharan Africa. Contrarily, there are no published reports concerning genetic 71 diversity of maize germplasm in the Sahara desert or even in most North African 72 countries. Saharan maize has evolved from tropical introductions made by Spanish muslin pilgrims during the XVIth Century or from subsequent reintroductions by 73 74 Turkish or French conquerors (Revilla et al. 1998; Sanou et al. 1997; Weatherwax 75 and Randolph 1955). Algeria is the country with the largest portion of Sahara desert. 76 Recently, maize germplam has been collected in the Algerian oasis, and that 77 collection is being studied nowadays. The remains of uncertain origin grown in the 78 oasis of the Sahara desert could constitute a unique germplasm pool because of its 79 history and its potential value as sources of alleles for tolerance to biotic or abiotic 80 stress. 81 Besides collecting and conserving the Saharan maize germplasm, there are 82 a number of interesting question to investigate, such as the diversity available, the 83 origin of the germplasm or its potential value for breeding. In this first work, we

84 adopt a breeding perspective and investigate the adaptation and agronomic

85 performance of a representative sample of Saharan maize in temperate areas.

87 Materials and methods

88	A collection of maize populations from the Algerian Sahara is conserved in
89	the National School of Agronomy of Algiers. From that collection, a sample has
90	been evaluated for adaptation and agronomic performance in three distinct
91	environments (Table 1). Saharan sample consisted on 10 open-pollinated
92	population's representative of the maize grown in the Saharan oasis. These
93	populations were assayed along with 13 cultivars from the dry Spain, four cultivars
94	from the humid Spain, four cultivars and three single crosses from the US Corn Belt,
95	and three crosses among cultivars from these temperate origins. The trials were
96	carried out in 2009 and 2010 in Pontevedra, Saragossa and Algiers. Pontevedra (42 $^\circ$
97	24', 8' 38'N, altitude 20 m) is in the humid Spain; Saragossa (41° 41' N, 0° 49' W,
98	altitude 250 m) is in the dry Spain; and Algiers (36 ° 47 ' N, 2 ° 03' E, altitude 32 m)
99	is in the sub humid North of Algeria.
100	The cultivars were evaluated in randomized complete block designs with
101	three replications. Each experimental plot consisted of two rows with 25 hills per
102	row and one grain per hill. Rows were spaced 0.80 m apart and hills were spaced
103	0.18 m achieving a final plant density of approximately 69000 plants ha ⁻¹ . Currently
104	accepted management and cultural practices were used in all trials including
105	frequent irrigation at Saragossa, less frequent irrigation at Algiers, and no irrigation
106	at Pontevedra. We measured 17 traits related to adaptation and agronomic behavior
107	(Table 2).
108	Given the limited seed availability from the Algerian populations, they
109	were not evaluated in Algiers in 2009. Due to the poor performance of many of the
110	first set of populations evaluated in 2009 and the limited seed availability of the
111	Algerian populations, we chose a different set of cultivars for 2010, except for three
112	common checks that were repeated in all environments. Therefore, the cultivars
113	evaluated in each environment were not the same except for three cultivars that were

114	repeated in all environments in order to be used as common references:
115	EPS13(FR)C3, EPS14(FR)C3, and BS17C5, from humid and dry Spain and from
116	the US Corn Belt, respectively. In order to compare the cultivars across
117	environments, for each trait, means were corrected for year effect and for location
118	effect by using the deviation of means of common cultivars in single locations and
119	years from the overall mean as follows:
120	
121	$Mvyl = \Sigma [Mi + (My - Mt) + (Ml - My')]$
122	Where:
123	Mvyl is the mean of each cultivar (v) corrected by year (y) and location (l) effects
124	Mi is the raw mean of each cultivar in the l location and y year
125	My is the mean of the three common cultivars in y year
126	Mt is the mean of the three common cultivars across years
127	Ml is the mean for the cultivars evaluated in the l location
128	My' is the mean of the common cultivars across locations
129	
130	The relationships among environments were estimated by means of Pearson
131	correlation analyses between each pair of locations (Pontevedra, Saragossa and
132	Algiers) for six traits presumably affected by environment: Stand, male and female
133	flowering, anthesis – silking interval, grain yield and moisture. Analyses of variance
134	were performed for each trait, being the sources of variation locations, years,
135	cultivars, repetitions and their interactions. Cultivars and locations were considered
136	fixed effects, while years and interactions with random factors were considered
137	random effects. Comparisons of means were performed for each trait using Fisher's
138	protected least significant difference (LSD) and the standard error of difference
139	(SED) at $P = 0.05$ (Steel et al. 1997). LSD and SED for each comparison were
140	calculated from the analysis of variance of the common populations for the

- 141 corresponding environments or group of cultivars. Analyses were made using GLM
- 142 procedure of SAS (SAS Institute 2005).
- 143

144 **Results and discussion**

145

146 The individual analyses of variance for each environment showed significant 147 differences among cultivars for all traits except for Algiers in 2010, wherein 148 differences were not significant for stand, flowering dates, anthesis - silking interval 149 (ASI), and grain moisture (data not shown). Combined-over-locations analyses of 150 variance in 2009 and 2010 revealed significant genotype-by- environment 151 interactions (GE) for most traits. Noteworthy, interactions were always significant 152 for early vigor, yield and moisture. GE was significant for all traits except plant 153 height in 2009, while in 2010 they were only significant for half of the traits, 154 including yield and moisture. Significant GE was often of rank rather than of 155 magnitude. This high frequency of significant effects and interactions is normal for 156 such a wide range of diversity in populations and environments (Revilla et al. 2006; 157 Romay et al. 2010). We can conclude from these analyses that adaptation and 158 agronomic performance of these genotypes should be restricted to each specific 159 environment. These analyses of variance are consistent with the wide climatic 160 adaptation range of the genotypes, as stated by Ruiz Corral et al. (2008) for a 161 collection of Mexican landraces. 162 Diversity among environments were studied through correlation analyses of 163 the performance of each cultivar in each environment for six traits associated to 164 maize adaptation, namely stand, male and female flowering, ASI, yield and grain 165 moisture (Table 3). Female and male flowering were consistent across environments 166 based on the reasonably high correlations between environments for these traits. 167 Considering all traits together, correlations were highest between Pontevedra (humid 168 Spain) and Algiers (sub humid Northern Africa) for male (0.93) and female (0.91) 169 flowering and ASI (0.55), and between Pontevedra and Saragossa (dry Spain) for 170 yield (0.84). Similarities and dissimilarities could be explained because weather

171	conditions of Pontevedra (humid and mild temperature) were more similar to those
172	of Algiers (sub humid and mild temperature) than of Saragossa (dry and
173	continental). Contrarily, high correlation between Pontevedra and Saragossa for
174	yield can be due to similar agronomical practices because both research institutes
175	have long tradition growing maize, while maize is a new crop in the Algerian field.
176	On the other hand, moisture data in Pontevedra was not correlated with the other two
177	locations because Pontevedra has high relative humidity at harvest, as well as twice
178	the rainfall of Algiers and four times the rainfall of Saragossa. Our results show that
179	these three environments are clearly diverse and most of the evaluated populations
180	were able to grow and produce grain in most environments, which would allow
181	using these populations as potential sources of favorable genes for diverse uses.
182	Evaluations in diverse environments allow plant breeders either the identification of
183	specifically adapted cultivars for each environment (Gomes et al. 2000; Abera et al.
184	2004; Setimela et al. 2007) or with wide ranges of adaptation and specific aptitudes
185	of cultivars for diverse environments (Gomes et al. 2000; Setimela et al. 2007).
186	The main purpose of this research is evaluating adaptation of the Saharan
187	maize to temperate conditions. Even though significant GE requires appropriate
188	analyses by environments, we can draw some general conclusions from means
189	across environments (Table 4). The five Saharan populations evaluated in all
190	locations in 2010 had a reasonably good germination while the five evaluated in
191	2009 had poor germination (<50%) in the Spanish locations. Low germination could
192	be due to poor seed conservation; therefore, seed viability should be urgently
193	checked and the seed renewed for the samples with poorer performance. After
194	emergence, Algerian populations were able to grow without any problem, actually
195	their early vigor was between 4 and 5.9; being three of them significantly more
196	vigorous than the weakest maize populations from Spain or the USA. Similarly,
197	stand was normal or even high for the Algerian populations.

198	Considering that these populations come from a semitropical area (< 30°
199	N), we could expect some problems with flowering and grain production. Although
200	we have no data concerning the flowering time in their original growing area, seed
201	providers informed that their growing season is short. In temperate locations, these
202	populations had medium growth cycle with a female flowering between 67 and 84
203	days, a male flowering between 68 and 89 and a normal ASI (around 2 days) (Table
204	4). Therefore, we can assume that there were no major constraints for growing these
205	populations under temperate conditions, even if their cycle was delayed. Although
206	half of the shortest populations were from Algeria, plant growth was normal, with
207	plant height between 127 and 188 cm and ear height between 35 and 112 cm.
208	The major handicap for using these populations under temperate conditions
209	is their poor ability for seed production. Actually, the adjusted yields reported in
210	Table 5 are not significantly different from 0 for all the Algerian populations grown
211	in Spain in 2009. Even though all cultivars produced some grain, when the figures
212	were adjusted by year and location effects, the results were close to zero. Contrarily,
213	the yield of the Algerian populations grown in 2010 was not significantly different
214	from most of the temperate populations. Nevertheless, the Algerian populations had
215	values of kernel weight and grain moisture similar or below those shown by
216	temperate populations. Furthermore, the values of prolificacy for most Algerian
217	populations are above those of the temperate populations and hybrids. The
218	agronomic values of these Saharan populations were within the range of most
219	autochthonous populations (Revilla et al. 2006; Romay et al. 2010).
220	Given that the GE interaction was often of rank, we have to pay attention to
221	adaptation for each environment (Table 6). The GE for yield was so important that
222	the highest yielder in Saragossa was the classical hybrid B73 x Mo17, that was
223	surpassed by other hybrids and even some inbred x population crosses in
224	Pontevedra, while in Algiers the highest yield corresponded to some populations. In

225	2009, the Algerian populations were not evaluated in Algiers due to limited seed
226	availability, but they had a very low yield and their ranks for yield were very similar
227	between both Spanish locations. The rank variations between Pontevedra and
228	Saragossa were more frequent for female flowering, particularly for the Algerian
229	population DZTAD that was earlier in Saragossa than in Pontevedra. GE was more
230	important for ASI, which was larger in Saragossa due to the drier and warmer
231	conditions compared to Pontevedra. The rank of the Algerian populations for ASI
232	was shorter in Pontevedra than in Saragossa. Grain moisture was obviously highest
233	in Pontevedra and variations between Pontevedra and Saragossa were also large.
234	However, such variations were not very important for the Algerian populations.
235	In 2010, GE was significant for yield and grain moisture and interactions
236	were of rank, rather than of magnitude (Table 6). As hybrids were not included in
237	the trials of 2010, the highest yielders were the improved synthetic EPS14(FR)C3
238	from dry Spain in Algiers, the local population from southern Spain Basto in
239	Pontevedra, and the improved Corn Belt synthetic BS17C5 in Saragossa. The strong
240	GE was shown by EPS14(FR)C3 that was seventh for yield in Pontevedra, Basto
241	that was ninth in Algiers, and by BS17C5 that was fifth in Pontevedra. Conversely,
242	the lowest part of the rank for yield corresponded to the Algerian population BZBSA
243	in all locations. Nevertheless, the GE affected similarly the Algerian populations;
244	e.g., concerning moisture, the trial of Algiers had the largest number of
245	discrepancies, affecting particularly the Algerian populations; the most extreme
246	interaction was for DZBSA that had the third moisture in Algiers and the ninth and
247	tenth in Pontevedra and Saragossa, respectively. GE was not significant for
248	flowering or ASI in 2010, and actually some populations had some consistent
249	positions in the ranks of the three locations, particularly DZBTM was the fourth in
250	the rank of late populations, while and DZBSA was the earliest population in all
251	locations. Finally, the rank for ASI was consistent for most populations. However,

252 there were also important rank variations for ASI, particularly for BS17C5 that had 253 the largest value in Pontevedra and was sixth in Algiers and Saragossa, or for 254 DZAAS that had the shortest ASI in Saragossa and one of the largest in Algiers, 255 although these values were not significantly different. 256 As conclusions, adaptation of Saharan populations to temperate 257 environments was sound, although environmental effects between years could be the 258 main limiting factor. This is in agreement with previous reports showing that 259 climatic limits of maize are wide, indicating that maize has evolved to great 260 adaptability and great expansion its geographic range (Ruiz Corral et al. 2008). 261 However, the tropical populations evaluated by Ruiz Corral et al. (2008) were 262 adequately adapted solely within the limits of tropical environments and differences 263 in adaptation depended on genotypes. Therefore, we can search genes for adaptive 264 features (e.g. severe temperature tolerance) which, according to Hawtin et al. (1996), 265 may be found in extreme environments, or to other purposes (e.g. photoperiod 266 insensitivity) that may have evolved away from primary centers of origin. Indeed, 267 we could also expect that semitropical maize will need selection for tolerance to 268 temperate conditions in order to be adequate for breeding programs in temperate 269 areas (Soldati et al. 1999). 270 271 Acknowledgements 272 This research was supported by the Agencia Española de Cooperación y Desarrollo

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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	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	1	
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 30° 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	Mg ha ⁻¹
	moisture	
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.

		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	

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Table 4. Adju	sted ^a means of vegetat	ive traits from	the evaluatio	n of maize	cultivars	s from fou	ur diverse origi	ins in Ponteve	dra (humid Sp	ain, DSP),	
Saragossa (dr	y Spain, HSP) and Alg	tiers (ALG) in 2	2009 and 201	0.							
									Anthesis-		
				Emer-	Early		Female	Male	Silking	Plant	Ear
Origin	Cultivar	Eva	luation	gence	vigor	Stand	flowering	flowering	interval	height	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
				14	1.6	7	2.0	2.1	1.22	17.8	18.7
	Total			5.60	0.71	3.0	0.91	0.93	0.55	7.27	6.73
					1.6	57	6.1	5.7	1.98		
	2009, HSP-DSP				0.78	27.8	2.96	2.78	0.96		
					1.5	24	4.1	4.1	2.18	19.7	
	2009 (excluding ALG)				0.72	11.8	2.04	2.04	1.08	9.54	
LSD (0.05)				11	2.2	18	3.1	3.3	1.39	19.1	
SED (0.05)	2010			5.3	1.04	8.40	1.87	1.55	0.66	9.11	
^a Means were	adjusted by location and ye	ear effects	as explained	l in Materia	lls and M	ethods					

Table 5. Adjusted ^a means of ear traits from the evaluation of maize cultivars from four diverse origins												
in Pontevedra (humid Spain, HSP), Sara	gossa (dry Spai	n, DSP)	and Algie	ers (ALG) in 2009 and	d 2010.					
				Grain	Grain	Kernel	Ears /					
Origin	Cultivar	Evalı	ation	yield	moist.	weight	plant					
			Loc -	Mg ha ⁻								
		Year	ation	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		2009	H-									
	KAAAAd		DSP	0.00 ^b	16.5	22.9	1.68					
ALG		2009	H-									
	KHGTAd		DSP	0.00 ^b	19.3	37.6	1.67					
ALG		2009	H-									
	MHAd		DSP	0.60	16.1	21.9	1.30					
ALG		2009	H-									
	RGNAd		DSP	0.00 ^b	16.1	19.9	1.67					
ALG		2009	H-									
	ZDTAd		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
				1.13	1.8	11.2	0.14
	Total			0.50	0.79	2.60	0.06
LSD (0.05)	2009, HSP-DSP			2.98	2.0		0.32

SED (0.05)				1.45	1.04		0.15
				3.07			0.20
	2009 (excluding ALG)			1.53			0.09
				1.54	3.8		0.34
	2010			0.73	1.97		0.16
^a Means were adjust	ed by location and year eff	ects as ex	xplained i	in Materi	als and N	Aethods	
^b This value was obt	ained after correcting the r	aw data f	for location	on and ye	ar effect	, although th	ese
cultivars produced a	ctually some grain						
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Table 6. Adjusted ¹ means per lo	cation an	d year o	of four	traits rela	ted to adap	ptation from	n the eval	luation o	f maize	cultivars	from four	diverse	
origins in Pontevedra (humid Sp	ain, HSP), Sarag	gossa (o	lry Spain	, DSP) and	l Algiers (A	ALG) in 2	009 and	2010.				
	ALG	HSP	DSP	ALG	HSP	DSP	ALG	HSP	DSP	ALG	HSP	DSP	
	Femal	e flowe	ring	Anthesi	s - silking	interval							
Cultivar	(days)			(days)			Yield (N	/Ig g ⁻¹)		Grain moisture (g kg ⁻¹)			
				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)	3.8	3.6	2.5	2.83	2.35	1.97	1.36	3.38	0.53	3.7	1.7	0.9
SED (0.05)	1.89	1.81	1.24	1.40	1.18	0.98	0.67	1.69	0.26	1.85	0.86	0.43
				Ŋ	Year 2010		1				I	
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