Euphytica (2015) 205:219–230
DOI 10.1007/s10681-015-1430-3

Breeding maize for traditional and organic agriculture

Pedro Revilla · Jose Ignacio Ruiz de Galarreta · Rosa Ana Malvar · Arsenio Landa · Amando Ordás

Received: 7 August 2014 / Accepted: 17 March 2015 / Published online: 28 March 2015

Abstract Breeding maize (*Zea mays* L.) for traditional agriculture can increase quality and added value of agricultural products and allow the recovery of traditional foods. The objectives of this work were to evaluate improved open-pollinated populations under organic and conventional agriculture in order to determine the effects of selection for yield and flour yield and the relationship between agronomic and quality traits under both cropping systems. We have selected open-pollinated maize populations for flour yield and bakery quality under organic conditions, improved them under conventional conditions and evaluated the breeding programs under organic and conventional conditions. Breeding was efficient for grain and flour yield under organic agriculture for Meiro (an open-pollinated population with black grains) but not for the other populations neither in organic nor in conventional conditions. Yield ranks of varieties were moderately correlated under both conditions, and genotype × environment interaction (GE) was significant for most traits when the analyses of variance were made over all environments but also when organic and conventional environments were separated. GE was higher under organic agriculture. Correlations between traits were higher under conventional agriculture and there were important discrepancies between correlations in organic and conventional agriculture. We concluded that selection under conventional agriculture was efficient for one population under organic agriculture. Selection under the target environment could increase the possibilities of success.

Keywords Organic agriculture · Yield · Quality · Germplasm · Breeding

P. Revilla (✉) · R. A. Malvar · A. Ordás
Misión Biológica de Galicia, Spanish Council for Scientific Research, Apartado 28, 36080 Pontevedra, Spain
e-mail: previlla@mbg.csic.es

J. I. R. de Galarreta
NEIKER-Instituto Vasco de Investigación y Desarrollo Agrario, Apartado 46, 01080 Vitoria, Spain

A. Landa
Promotora Orxeira S.A, Ermille, Lobeira, 32897 Ourense, Spain

Introduction

Traditional agriculture was similar to organic agriculture until the advent of inorganic fertilizers and phytosanitary synthetic products in the second half of the Twentieth Century. According to Kovacevic and Lazic (2012), organic agriculture is based on strong ecological principles and the absence of application of agrochemicals, GMO, etc. Organic agriculture is a holistic way of farming besides production of goods of high quality; conservation of the natural resources and richness of biodiversity.

When breeding crops for traditional or organic agriculture, some breeders consider that selection need not be accomplished under both organic and conventional agriculture because varieties developed for conventional agriculture are also suitable for organic agriculture (Ardelean et al. 2012; Burger et al. 2008; Lorenzana and Bernardo 2008). Contrarily, other authors emphasize the need to develop effective strategies for improving crop performance in organic systems through plant breeding and that varieties should be improved for specific adaptation (Löschenberger et al. 2008; Murphy et al. 2005; Wolfe et al. 2008; Kovacevic and Lazic 2012; Van Bueren et al. 2011). These last authors have suggested that breeding for organic conditions has specific requirements for some crops and that cultivars that perform very well under conventional agriculture are not interesting for organic agriculture. Nevertheless, no specific maize breeding program has been reported so far although Rodrigues de Oliveira et al. (2011) point out that election of base breeding material must be made in the specific environment for the expression of favorable alleles that confer advantages for adaptation to this system. Some authors also tested under organic conditions hybrids released under conventional conditions and found an acceptable agreement (Lorenzana and Bernardo 2008; Burger et al. 2008); however, yield was reduced under organic conditions (Burger et al. 2008). Several breeders have released improved varieties under conventional agriculture, but there are few reports of plant breeding under organic agriculture.

Maize open-pollinated populations have been cultivated for centuries in traditional agriculture and selected for adaptation and quality but have lower yield than modern hybrids under conventional agricultural conditions. Since the introduction of maize in Europe, diverse maize varieties have been selected for adaptation to a wide range of environments and consumer preferences. Such wide genotypic and environmental diversity can have caused also significant genotype × environment interactions with specific adaptation to environmental conditions and farmer's preferences (Duarte et al. 2005; LeFord and Russell 1985; Malvar et al. 2008; Revilla et al. 2008).

Maize was traditionally used for bread, which is a peculiarity of the north of Spain and Portugal but also of other countries. Maize bread is made traditionally with whole flint maize grains. Consumers prefer flint grains because their flour has better cooking characteristics and flavor than dent grains (Landa et al. 2006). Quality requirements are important for human consumption (Watson 1988) but bread quality is not defined for maize as for wheat and baking quality is lower for maize than for wheat (He and Hoseney 1991). Although there are no defined criteria for bakery quality for maize bread, some criteria are generally accepted, such as large grain size, uniformity, high density, and lack of physical damage, pests, and diseases (Alonso Ferro et al. 2008; Serna-Saldivar et al. 2001; Watson 1988). Yellow maize is used normally for feed because it is a source of carotenoids for animals (Troyer 1999), while white maize is preferred for human consumption because pigments cause strong aroma and flavor when cooked (Poneleit 2001). Moreover, yellow or black grains are preferred in some areas (Serna-Saldivar et al. 2001; Landa et al. 2006). Actually, in previous studies we concluded that differences in pigment content are directly related to antioxidant activity in maize grains and that traditional methods for maize production and processing maintained quality, pigment content and antioxidant activity (Revilla et al. 2012; Rodríguez et al. 2013).

Revilla et al. (2008) identified some local varieties with white, yellow, and black grains, appropriate for bakery that performed well under organic agriculture. In that report we concluded that there was no clear relationship between yield and quality and the varieties improved under conventional agriculture are adequate for organic agriculture as well. Therefore, we began some breeding programs for improving open-pollinated varieties for agronomic performance under conventional agriculture focusing on traditional and organic agriculture.

With the introduction of hybrids under intensive cropping systems, the local populations and the traditional uses of maize have been abandoned. The reintroduction of improved traditional varieties suitable for organic agriculture and for manufacturing products for human consumption and organic agriculture would fit the social demands for higher quality and safe foods. The objectives of this work were to evaluate under organic and conventional agriculture several maize varieties improved for grain yield or quality along with other open-pollinated populations of maize grown in the past by farmers under traditional agriculture to find out if selection for grain yield and flour yield under conventional agriculture was useful also for organic agriculture, and to investigate the relationship between agronomic and quality traits under both cropping systems.

Materials and methods

Plant material and breeding programs

We evaluated for agronomic performance and grain quality under organic and conventional agriculture ten open-pollinated populations, potentially valuable for maize bread or bakery use (Table 1). Five of these open-pollinated populations (Donostia, Meiro, Rebordanes, Sarreaus, and Tuy) have been improved for grain yield or flour yield during one or three cycles. The breeding program for Donostia was carried out in the experimental field of NEIKER (Álava) and consisted on evaluating 100 S_1 families and recombining the 20 S_1 families with the higher ability for making "talo", a kind of maize bread. One cycle of selection was carried out. The breeding program for Meiro, Rebordanes and Sarreaus was carried out in the experimental field of Misión Biológica de Galicia (Pontevedra) and consisted on recombining the 20 S_1 families with highest flour yield and quality for maize bread from 100 S_1 families. Flour yield was obtained by multiplying yield by proportion of flour produced after grinding 50 g of whole grain in a coffee mill for 1 min, and sieving for 1 min in a sieve with 1 mm orifices (Table 2). Quality for maize bread was assessed by a panel that evaluated maize breads made from the S_1 families with flour yield above average. Bread was made following a traditional recipe (Revilla et al. 2008). Two cycles of selection were carried out for those three populations. Finally, the breeding program for Tuy was carried out in a similar way, but in this case the selection criterion was grain yield. Three cycles of selection were carried out for this population.

Table 1 Maize varieties, origin, type of germplasm and growth cycles evaluated in Northern Spain under organic and conventional agriculture

Genotype	Origin	Cycle, grain color
Carballeira	Galicia	Medium, black
Donostia	Basque Country	Medium, yellow
DonostiaC1	Basque Country	Medium, yellow
Martikoenea	Basque Country	Medium, yellow
Meiro	Galicia	Medium late, black
Meiro(P)C1	Galicia	Medium late, black
Meiro(P)C2	Galicia	Medium late, black
NKThermo	Commercial check	
Oroso	Galicia	Medium, yellow
PR36B08	Commercial check	
Rebordanes	Galicia	Medium, white
Rebordanes(P)C1	Galicia	Medium late, black
Rebordanes(P)C2	Galicia	Medium late, black
Sarreaus	Galicia	Early, yellow
Sarreaus(P)C1	Galicia	Early, yellow
Sarreaus(P)C2	Galicia	Early, yellow
Tuy	Galicia	Medium, yellow
Tuy(S)C1	Galicia	Medium, yellow
Tuy(S)C2	Galicia	Medium, yellow
Tuy(S)C3	Galicia	Medium, yellow
Txalin	Basque Country	Medium, yellow

Experimental design

The resulting 20 open-pollinated maize populations and improved cycles from northern Spain and two commercial checks were evaluated in two farmers' fields in Galicia and in the Basque Country under organic and conventional agriculture. Five organic environments and five conventional environments were used between 2010, 2011 and 2012 (Table 2). The 22 genotypes were evaluated in trials that followed an experimental design of randomized complete blocks with three replications. The experimental plots of 10 m^2 had a density of 60,000 plants ha^{-1}, with rows separated 0.8 m and plants within rows 0.21 m. Agricultural practices followed the recommendations of organic agriculture, i.e. nutrients were supplied by adding manure, weeds were removed mechanically, and no chemical treatment was used. Under conventional agriculture, current practices were the usual in the area with inorganic fertilizers, use of herbicide and no irrigation. On each plot we measured early vigor (scale from 1 = weak to 9 = vigorous on 5-week old plants), plant appearance (the same scale from 1 to 9 but after flowering), days to silking, ears per plant, grain yield (Mg ha^{-1} at 140 g H_2O kg^{-1}), flour yield (Mg ha^{-1} calculated as described above for the selection programs), grain moisture (g kg^{-1}), 100 grain weight, milling test (% of grinds), and grain density (g ml^{-1}). Milling test was an estimation of the resistance of grains to produce flour in a laboratory mill; it was defined as the percentage of flour produced

Table 2 Environments used for selection and evaluation of 23 maize varieties, improved cycles and checks in Northern Spain under organic and conventional agriculture

Environment	Location	Year	Type	Latitude	Longitude	Altitude (m)
1	Lobeira (Ourense, Galicia)	2010	Organic	41°60′N	8°02′W	600
2		2011				
3		2012				
4	Heredia (Álava, Basque Country)	2010		42°53′N	2°26′W	567
5		2012				
6	Pontevedra[a] (Galicia)	2010	Conventional	42°24′N	8°38′W	20
7		2011				
8		2012				
9	Arkaute[a] (Álava, Basque Country)	2010		42°51′N	2°38′W	512
10		2011				

[a] Selection sites

in a limited time. The milling test consisted on grinding 50 g of whole grain in a coffee mill for 1 min, sieving for 1 min in a sieve with 1 mm orifices, and weighting the remaining fraction. Milling test was calculated as 100 × (grain weight − remaining fraction)/grain weight. The method for estimating grain density was to pour 50 g of whole grain in a test-tube containing 50 ml of 95 % ethanol, and to record the final volume of the mixture. Grain density was estimated as grain weight/(final volume − initial volume).

Statistical analyses

Analyses of variance were carried out using the procedure GLM of SAS (SAS Institute 2010) with 10 environments. Each environment is the combination of one year and one location. Five environments were under conventional conditions and 5 under organic conditions. First, we made combined analyses of variance over the ten environments in order to check the genotype × environment interaction (GE) and considering random all effects except genotypes. We carried out analyses of variance by type of agriculture (organic and conventional) and considering random all effects except type of agriculture. Then we carried out analyses of variance by environment in order to check if interactions were of rank or of magnitude, considering also random all effects except genotypes.

Comparisons of means were made by using the Fishers' protected LSD at P = 0.05. Pearson (simple) and Spearman (rank) correlations were calculated between traits with the procedure CORR of SAS. To analyze the efficiency of the selection programs, values of 0, 1, 2, and 3 were assigned to the corresponding cycles of selection, and simple linear regression analyses incorporating random effects in the model [environment and replication (environment)] were performed for yield, flour yield and milling test (dependent variable) and cycles of selection (independent variables).

Results

The combined analyses of variance showed that differences between types of agriculture (organic or conventional) were not significant for the main agronomic traits (grain moisture or yield) but differences were significant for most quality traits, including 100 kernel weight, milling test and grain density (Table 3). Differences between varieties were significant for few traits and the triple interaction environment × type × variety was significant for most traits.

When we checked the effects of selection for yield, flour yield, and milling test, we found out that most regression coefficients were not significant, with most of the significant coefficients being negative (Table 4). Only Meiro significantly increased flour yield under organic conditions while it decreased for Sarreaus, and the response was not significant under conventional conditions. The response was similar for yield, except for Donostia with a significant decrease

Table 3 Degrees of freedom (df) and mean squares of the main agronomic and quality traits from the analyses of variance of 22 maize varieties, improved cycles and checks (see Table 1) evaluated under organic and conventional conditions in five environments (see Table 2) in Northern Spain

Sources of variation	Df	Grain moisture (g/kg)	Yield (kg/ha)	Flour yield (kg/ha)	100 kernel weight (g)	Milling test (%)	Grain density (g/cm^{-3})
Environment	3	776.84**	768,115,455**	611,681,861**	1784.13**	177.02**	0.0516*
Type	1	367.72	46,217,972	41,889,517	401.28**	17.09*	0.0619**
Repetitions (env.)	8	18.81**	4,924,875**	3,874,024**	11.75	23.08**	0.009*
Variety	21	64.68**	9,129,773	6,709,382	154.65**	9.7**	0.0054
Env × Var	57[a]	11.42	8,713,440	7,021,260	36.23	3.79	0.0047
Type × Var	21	38.36	1,857,704	1,482,925	19.26	2.68	0.0044
Env × Type × Var	53[b]	134.27**	15,912,305**	11,640,576**	37.16**	4.25**	0.0053*
Error	287[c]	3.067	987,340	817,366	9.076	2.004	0.00357

[a] DF (Env × Var) = 54 for moisture, yield and flour yield

[b] DF (Env × Type × Var) = 35 for moisture and yield and 34 for flour yield

[c] DF (Error) = 263 for moisture, 257 for yield, 247 for flour yield, and 279 for density

*, ** Significant at P = 0.05 and 0.01, respectively

of yield in both organic and conventional conditions. For milling test, Rebordanes increased grain hardness under both conditions and Sarreaus decreased hardness under conventional conditions.

In the combined analyses of variance over the ten environments, genotypes were significantly different for all traits except early vigor, and environments for all traits except early vigor and plant appearance. Genotype × environment interaction (GE) was significant for all traits except ears per plant and grain density and interactions were mainly of rank. We carried out analyses of variance by type of agriculture (organic vs. conventional) and found that the genotypes were significantly different for all traits except early vigor, plant appearance and silking under conventional agriculture, and for all traits except early vigor, silking, ears per plant and grain density under organic conditions. Environments were also significantly different for most traits, and GE was significant for most traits including grain yield, flour yield and grain moisture. Interactions were mostly of rank (Tables 5, 6).

Combined means for flour yield were highest for the commercial checks and Meiro(P)C2 (Table 4). Ranks under organic and conventional conditions were similar. Both commercial checks had the highest yield in both conditions. Many varieties were not significantly different for milling test from those with hardest grains across conditions, namely Carballeira, Rebordanes, and Getaria. The softest grains under organic conditions were those of Meiro(P)C2, and of NKThermo under conventional conditions, while across conditions the softest grains were produced by Oroso, the commercial check PR36B08, and Sarreaus(P)C2. Rank correlations between organic and conventional conditions were moderate for milling test ($r^2 = 0.65$, $P = 0.001$), flour yield ($r^2 = 0.70$, $P > 0.001$), and yield ($r^2 = 0.69$, $P > 0.001$) (Fig. 1).

The highest and the lowest yielder for each location were different both between and among organic and conventional conditions (Table 5). However, the most stable across organic conditions was Meiro(P)C2 followed by Tuy(S)C2 and NKThermo. Under conventional conditions, the most stable was the commercial check PR36B08.

GE was significant for milling test under conventional conditions but not under organic conditions. Differences among genotypes were not significantly different for three organic and one conventional environments. The hardest grains across locations were those of Rebordanes(P)C2 both under organic and conventional conditions followed by Tuy (Table 6). The varieties with hardest grains differed for each location except for Rebordanes(P)C2 and Carballeira that had the hardest grains in two and three locations, respectively. Differences among genotypes for early vigor were not significant in either type of agriculture, for plant appearance only in organic conditions, and for silking, ears per plant, and grain

Table 4 Mean yield, flour yield (kg ha^{-1} at 140 g kg^{-1} grain moisture) and milling test (% of grinds) for 22 maize varieties, improved cycles and checks (see Table 1) evaluated in five environments (see Table 2) in Northern Spain under organic (Org) and under conventional (Con) agriculture and significant coefficients of regression for cycles of selection

	Flour yield		Yield		Milling test	
	Org	Con	Org	Con	Org	Con
Carballeira	4118def	5199cd	4672def	5456def	11.87a	11.34ab
Donostia	4148def	5194cd	4570def	5715c–f	9.25de	10.03b–f
DonostiaC1	3338ef	5512bcd	3347 fg	4987ef	9.71de	10.42a–e
Donostia b[a]			−1222.6*	−1170.7*		
Getaria	1679g	3917d	1884 g	4406f	11.00abc	11.20abc
Martikoenea	5830abc	7831ab	6503bc	8727ab	10.27bcd	10.11a–f
Meiro	5096bcd	6614abc	5641bcd	7274b–e	9.57de	9.51d–g
Meiro(P)C1	5110bcd	6026a–d	5644bcd	6920b–f	9.61de	9.80b–g
Meiro(P)C2	6205ab	6830abc	6833b	7584a–d	9.01e	9.47d–g
Meiro b[a]	554.6*		596.0*			
NKThermo	6860a	8129a	9720a	8140abc	10.24bcd	8.30g
Oroso	3129f	6600abc	3429efg	6389b–f	9.53de	8.80gf
PR36B08	5747abc	8107a	10592a	10052a	9.47de	8.89efg
Rebordanes	4451c–f	5982a–d	4951c–f	6118c–f	9.80cde	10.27b–h
Rebordanes(P)C1	4785cd	6184a–d	5318bcd	6878b–f	10.24bcd	10.72a–f
Rebordanes(P)C2	4035ef	4890cd	4528def	5711c–f	11.24ab	11.57a
Rebordanes b[a]					0.72**	0.51*
Sarreaus	4923bcd	5575bcd	5485bcd	6191b–f	10.09b–e	10.63a–d
Sarreaus(P)C1	4560cde	5041cd	5056b–f	5583c–f	9.77de	10.47a–d
Sarreaus(P)C2	4187def	5513bcd	4613def	6054c–f	9.63de	9.37d–g
Sarreaus b[a]	−368.4*		−435.8*			−0.68**
Tuy	4690cde	6162 a–d	5219cde	6872b–f	10.15b–e	10.84a–d
Tuy(S)C1	4793 cd	6239 a–d	5308bcd	6482 b–f	9.68de	10.06a–f
Tuy(S)C2	4965bcd	6562abc	5513bcd	7255 b–e	9.80cde	10.37b–e
Tuy(S)C3	4715cde	6541abc	5147b–e	7293b–d	10.12b–e	10.56a–d
Tuy b[a]						
Txalin	5314bcd	5428 cd	6786b	5931c–f	10.30bcd	9.70c–g
LSD (5 %)	1407	2375	1797	2582	1.20	1.55

Means followed by the same letter within the same column are not significantly different (P = 0.05)

[a] Coefficient of regression of each trait on cycles of selection

$^{+}$, *, ** Significant at P = 0.1, 0.05, and 0.01, respectively

density only in conventional conditions (Table 7). The varieties with fewer days to silking were Sarreaus and its improved cycles, Donostia and its improved cycle, and Martikoenea, while those with high yield, such as Meiro and its improved cycles and the commercial hybrid PR36B08, were among those with the longest growth cycle. Grain moisture is another measure of earliness that has low correlation with silking (Table 8) but varieties with lowest grain moisture had also few days to silking and vice versa (Table 7). Varieties also performed differently for grain moisture under organic and conventional conditions. Ears per plant were below one under organic conditions while most varieties had around one ear per plant in conventional conditions and the lowest values were for Martikoenea followed by DonostiaC1 and Txalin.

Correlations between traits under organic and conventional conditions were different for grain yield

Table 5 Mean yield (Mg ha^{-1} at 140 g kg^{-1} grain moisture) for 22 maize varieties, improved cycles and checks (see Table 1) evaluated in ten environments (see Table 2) in Northern Spain under organic and conventional agriculture

Genotype	Organic conditions					Conventional conditions				
	1	2	3	4	5	6	7	8	9	10
Carballeira	2966.7c	2532.0cde	2787.0a–d	6999.7b–f	5146.3h	881.7a–d		5283.3de	8167.0cde	7491.3hg
Donostia	2717.0c	1825.3efg	1544.7e	7936.3a–e	8076.7g	1200.0a–d		2883.0fg	9791.0abc	8985.7fge
DonostiaC1	3321.7bc	1200.7 g	388.0f	7135.3b–f	8824.7 fg	99.5d		1580.7 g	8980.0b–e	7660.0hg
Getaria			1884.0de					4405.7ef		
Martikoenea	2862.3c	2110.7d–g		9144.7a	4689.3h	304.0dc			9110.0b–e	11151.7c
Meiro	4286.3abc	3228.3abc	2983.3a–d	7610.0a–f	11893.7bc	1261.0a–d		7227.3c	9427.0a–d	11,179.7c
Meiro(P)C1	2739.7c	3918.0a	2219.7b–e	7927.3a–e	10098.3def	1194.3a–d		7770.3c	9768.0abc	8945.7fge
Meiro(P)C2	5653.3a	3640.7ab	2884.3a–d	8520.0ab	11,413.7cde	1042.7a–d		9758.3b	8804.0b–e	10728.7c
NKThermo				7633.3a–e	13,468.3ab	1834.3ab		12,488.7a	7167.0e	11,071.7c
Oroso	2774.3c	1514.0fg		6000.0 fg	11807.3bcd	532.7bdc			10,645.0ab	7991.0fgh
PR36B08				6356.0efg	14,828.3a	2185.0a		13,248.0a	8523.0b–e	16,251.3a
Rebordanes	3300.3bc	2958.7bcd	3118.3abc	5353.3g	10,026.0ef	833.7a–d		6796.0 cd	7174.0e	9668.3dce
Rebordanes(P)C1	4169.0abc	2403.0c–f	2622.0a–e	8354.3ab	9042.3 fg	1091.0a–d		6394.3 cd	11578.0a	8449.3e–h
Rebordanes(P)C2	2604.7c	2234.5def	2587.7a–e	6580.0d–g	7869.3g	527.0bcd		5988.7cde	8662.0b–e	7667.0hg
Sarreaus	3561.0bc	1981.0efg	2035.7cde	7748.7a–e	12,099.3bc	521.0bcd		5934.0cde	9249.0b–e	9058.7d–g
Sarreaus(P)C1	3161.0bc	2534.7cde	2352.3a–e	6007.3 fg	11,225.7cde	1186.5a–d		5203.7de	7507.0de	6969.7h
Sarreaus(P)C2	3296.3bc	1196.0g	1541.0e	7679.7a–e	9354.0fg	749.0bcd		4361.7ef	9176.0b–e	8161.7e–h
Tuy	3066.7c	1907.0efg	3338.3a	8800.3a	8980.7fg	1075.3a–d		6359.3 cd	10458.0ab	9595.7c–f
Tuy(S)C1	3835.0abc	2366.3c–f	2400.7a–e	7994.0a–d	9943.3ef	1502.3a–d		6477.3 cd	9161.0b–e	8788.7efg
Tuy(S)C2	5085.3ab	2670.3cde	3153.0ab	8237.0abc	8417.3fg	603.3bcd		6046.0cde	9433.0a–d	12938.0b
Tuy(S)C3	3522.0bc	3176.3abc	3011.3abc	6667.0c–g	9358.3fg	1098.0a–d		7192.0c	8167.0cde	10,648.7dc
Txalin	3223.7bc			8488.7ab	8645.3fg	1549.3abc			9209.0b–e	7034.0 h
LSD (0.05)	1946.9	927.3	1100.3	1610.4	1739.4	1413.5		1872.8	2163.5	1639.5

Means followed by the same letter within the same column are not significantly different (P = 0.05)

Table 6 Mean milling test (% of grinds) for 22 maize varieties, improved cycles and checks (see Table 1) evaluated in ten environments (see Table 2) in Northern Spain under organic and conventional agriculture

Genotype	Organic conditions					Conventional conditions				
	1	2	3	4	5	6	7	8	9	10
Carballeira	11.74b–e	11.00a	13.34	9.94	13.34	10.8ab	13.20a	13.94a	9.94	9.26b–f
Donostia	9.06f	8.66b–f	10.34	7.86	10.34	10.74ab	11.00bc	10.80de	7.86	9.74b–e
DonostiaC1	10.06def	8.86b–e	12.20	8.54	12.20		13.00a	11.40bcd	8.54	9.60b–f
Getaria			11.00					11.20cde		
Martikoenea	11.94b–e	8.66b–f		9.46	11.00	9.60ab	10.26b–e		9.46	10.94ab
Meiro	11.46b–e	6.60f	10.86	8.06	10.86	8.34bc	10.46b–e	12.94a–d	8.06	7.74f
Meiro(P)C1	11.2fcde	7.14def	11.06	7.60	11.06	9.14ab	10.34b–e	12.80a–d	7.60	8.80c–f
Meiro(P)C2	9.66ef	6.94ef	10.06	8.34	10.06	8.60bc	8.80ef	11.60bcd	8.34	10.00b–e
NKThermo	10.90c–f			9.80		5.20c	8.94def	8.00f	9.80	8.54def
Oroso	12.20bcd	8.66b–f		7.74		8.50bc	10.90bc		7.74	8.66c–f
PR36B08				9.46		8.46bc	8.20f	8.94ef	9.46	10.40a–d
Rebordanes	11.00c–f	7.46c–f	11.66	7.20	11.66	10.10ab	10.54bcd	13.06a–d	7.20	10.40a–d
Rebordanes(P)C1	11.80b–e	9.26abc	10.66	8.80	10.66	11.60ab	10.60bcd	13.60ab	8.80	9.00c–f
Rebordanes(P)C2	13.60ab	9.74ab	12.00	8.86	12.00	12.66a	11.66ab	12.60a–d	8.86	12.30a
Sarreaus	10.46c–f	9.14a–b	11.14	8.60	11.14	12.60a	10.00b–e	12.34a–d	8.60	9.60b–f
Sarreaus(P)C1	11.20c–f	9.14a–b	10.26	8.00	10.26	11.80ab	11.00bc	12.66a–d	8.00	8.86c–f
Sarreaus(P)C2	10.26def	9.66ab	10.26	7.66	10.26	9.00b	9.30c–f	11.54bcd	7.66	9.20b–f
Tuy	10.26def	9.40abc	11.14	8.80	11.14	10.46ab	11.66ab	12.74a–d	8.80	10.54abc
Tuy(S)C1	10.54c–f	8.66b–f	10.40	8.40	10.40	9.00b	10.14b–e	13.26abc	8.40	9.14b–f
Tuy(S)C2	9.94def	8.20b–f	11.14	8.60	11.14	10.94ab	11.14b	12.40a–d	8.60	8.80c–f
Tuy(S)C3	14.60a	9.14a–d	10.20	9.46	10.20	11.30ab	10.66bc	11.40bcd	9.46	10.20b–e
Txalin	12.74abc			7.86		11.74ab	13.00a		7.86	8.40ef
LSD (0.05)	2.32	2.10				3.58	1.72	2.30		1.94

Means followed by the same letter within the same column are not significantly different (P = 0.05)

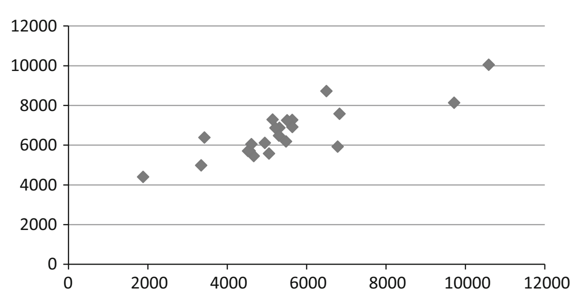

Fig. 1 Yield (kg/ha) under organic (y-axis) versus conventional (x-axis) agriculture of 22 maize populations, improved cycles and checks

and grain moisture under conventional ($r^2 = 0.79$, $P > 0.01$) and organic ($r^2 = -0.68$, $P > 0.01$) conditions, for flour yield with grain moisture under conventional ($r^2 = 0.78$, $P > 0.01$) and organic ($r^2 = -0.67$, $P > 0.01$) conditions (Table 8). Silking and early vigor, and silking and plant appearance had significant correlation under conventional conditions, but not under organic conditions. Agronomic traits had weak correlations with quality traits, except for milling test that had a negative correlation with yield, flour yield, and grain moisture; these correlations were even weaker under organic conditions.

Discussion

Breeding was efficient for Meiro that increased yield and flour yield only under organic conditions. However, selection was not efficient for the other open-pollinated varieties. Other authors have shown that intrapopulation recurrent selection with selfed families was efficient under conventional agriculture (Romay et al. 2011; Vales et al. 2001; Weyhrich

Table 7 Means for 22 maize varieties, improved cycles and checkcs (see Table 1) evaluated in ten environments (see Table 2) in Northern Spain under organic (Org) and conventional (Con) agriculture

	Early vigor (1–9)		Plan apperance (1–9)		Silking (days)		Ears per plant		Grain moisture (%)		100 grain weight (g)		Grain density (g cm^{-3})	
Genotype	Org	Con	Org	Con	Org	Con	Org	Con	Org	Con	Org	Con	Org	Con
Carballeira	3.3	3.3	3.7cde	4.0	69.8	82.8ab	0.78	0.88a	21.8def	20.7e–i	32.7c–f	35.1f–i	1.23	1.26ab
Donostia	3.3	2.7	3.3e	3.2	72.0	73.5gh	0.80	0.91a	21.0e–h	21.4d–h	36.3ab	39.8b	1.14	1.25abc
DonostiaC1	2.5	3.0	2.3f	2.5	67.8	71.9gh	0.55	0.54c	20.8fgh	19.7ij	36.1ab	39.7b	1.20	1.25a–d
Getaria						81.7abc	0.95	1.03a	36.4a	23.2abc	29.5gh	40.2b	1.12	1.20gh
Martikoenea	4.0	2.8	4.3abc	3.5	75.0	72.3gh	0.54	0.25d	20.2 g–j	20.4g–j	37.45a	42.9a	1.20	1.20b–f
Meiro	3.5	3.8	4.5ab	4.3	68.0	80.0b–e	0.74	0.92a	24.0c	21.4d–h	31.8d–g	35.2f–i	1.18	1.24a–e
Meiro(P)C1	3.5	3.5	4.5ab	4.5	75.5	86.6a	0.81	0.96a	26.0b	24.1a	28.2hi	33.6hij	1.20	1.30a
Meiro(P)C2	4.0	3.3	4.5ab	4.7	77.8	80.8a–e	0.75	0.95a	26.2b	23.4ab	30.9d–h	34.9ghi	1.17	1.20c–f
NKThermo	4.3	3.5	4.7a	4.3	78.3	79.5b–f		1.03a	18.0 k	21.1d–h	30.5e–h	32.0j	1.17	1.16 h
Oroso	4.3	3.7	4.3abc	4.7	78.0	81.4a–d	0.74	0.85ab	23.9c	24.0a	33.6bcd	33.4ji	1.23	1.21–cf
PR36B08	3.0	3.5	3.8b–e	3.7	79.7	81.3a–d		1.04a	19.0jk	21.6d–g	30.6e–h	35.5 fg	1.15	1.20f–h
Rebordanes	3.3	3.2	4.27a–d	3.7	75.5	76.8c–g	0.70	0.86ab	21.8d–g	21.4d–h	35.4abc	39.5cb	1.20	1.23a–f
Rebordanes(P)C1	3.8	3.8	4.27a–d	4.2	75.5	79.9b–e	0.75	0.95a	22.9 cd	21.5d–g	32.6c–f	35.4fgh	1.19	1.23d–f
Rebordanes(P)C2	3.0	3.3	2.0f	3.2	76.3	81.0a–e	0.76	0.93a	23.8c	21.4d–h	31.8d–g	35.0f–i	1.19	1.24a–e
Sarreaus	3.3	3.3	4.5ab	4.0	70.7	71.9gh	0.72	0.83ab	20.7f-i	19.2j	33.4b-e	35.4fgh	1.18	1.23b-f
Sarreaus(P)C1	4.5	3.2	3.5de	3.3	74.2	70.2 h	0.77	0.79abc	20.7f-i	20.5f-j	30.2fgh	34.0ghi	1.19	1.21c-f
Sarreaus(P)C2	3.8	3.3	3.3e	2.8	70.7	75.8d-h	0.70	0.92a	19.9hij	20.1hij	25.5i	29.8 k	1.17	1.22c-f
Tuy	4.2	3.0	4.3abc	4.5	68.7	76.0c-g	0.80	0.94a	22.0def	21.8def	33.7bcd	36.9def	1.17	1.24a-e
Tuy(S)C1	3.5	3.7	4.3abc	4.2	72.8	76.2c-g	0.72	1.00a	22.6 cd	22.1bcd	35.4abc	39.3bc	1.19	1.21def
Tuy(S)C2	3.8	3.0	3.8b-e	3.8	70.3	76.1c-g	0.77	0.92a	22.6cde	22.0cde	36.0ab	38.4bcd	1.19	1.21edf
Tuy(S)C3	3.3	3.8	3.8b-e	3.8	73.0	75.4e-h	0.91	1.06a	22.9 cd	20.9d–i	34.9abc	37.7cde	1.20	1.2b–f
Txalin	3.8	3.3	4.3abc	3.8	70.8	73.8fgh		0.59bc	19.2ijk	20.3 g–j	36.2ab	35.8efg	1.21	1.21efg
LSD (5 %)			0.76			5.79		0.270	1.61	1.34	2.93	1.93		0.04

Means followed by the same letter within the same column are not significantly different (P = 0.05)

Table 8 Simple correlations for ten traits recorded in 22 maize varieties, improved cycles and checks (see Table 1) evaluated in ten environments (see Table 2) in Northern Spain under organic (below the diagonal) and conventional (above the diagonal) agriculture

	Early vigor	Plant appearance	Silking	Ears per plant	Grain moisture	Grain yield	Flour yield	100 grain weight	Grain density	Milling test
Early vigor		0.49*	0.43*		0.24	0.10	0.10	−0.51*	−0.14	−0.23
Plant appearance	0.55**		0.47*		0.56**	0.30	0.39	−0.24	−0.06	−0.19
Silking	0.14	0.15		0.39	0.40**	0.18	0.17	−0.44**	0.05	−0.08
Ears per plant			0.00		0.65**	0.74**	0.70**	−0.16	0.06	−0.19
Grain moisture	−0.07	−0.06	0.42	0.66**		0.79**	0.78**	0.00	0.09	−0.59**
Grain yield	0.35	0.53*	0.11	0.19	−0.68**		0.99**	0.07	0.00	−0.73**
Flour yield	0.33	0.48*	−0.10	0.06	−0.67**	0.97**		0.09	0.02	−0.76**
100 grain weight	−0.24	−0.07	−0.41	−0.35	−0.29	0.10	0.15		0.24	−0.02
Grain density	−0.23	−0.06	−0.35	−0.35	−0.25	0.07	0.15	0.28		0.01
Milling test	−0.30	−0.21	−0.17	0.18	0.28	−0.41**	−0.43**	−0.06	0.13	

*, ** Significant at P = 0.05 and 0.01, respectively

1998). The explanations of our results could be that the evaluation was carried out in different fields (with more stressful conditions) than those used for selection, that the variability available for yield was not enough or was exhausted early, or that the selection reached a ceiling for example in the second cycle of Tuy. Whatsoever the reason could be, it is also true that the selection programs were similarly inefficient for yield and for flour yield both under organic and conventional conditions. Accordingly, Burger et al. (2008) stated that no specific adaptation to conventional or organic agriculture was observed in maize hybrids and concluded that including organic experimental sites among the evaluation fields increased the chances of success when selecting for organic conditions. Similarly, Lorenzana and Bernardo (2008) concluded that high-yielding cultivars for organic systems can be developed by screening conventional inbreds and hybrids for their performance under organic systems. Boller et al. (2008) concluded that varieties of grasses should be chosen based on performance under organic conditions but yields in organic and conventional conditions were high enough to expect that selection under either condition would be similarly efficient. However, most of the breeding programs we carried out under conventional agricultural conditions in our station were not efficient when evaluated under organic conditions, suggesting that breeding programs carried out in the target environment could be more efficient, as other authors have concluded, e.g. Rodrigues de Oliveira et al. (2011) believe that maize breeding for organic conditions should be carried out in the target environment; Löschenberger et al. (2008) recommended a winter wheat breeding program specifically designed for organic agriculture since the election of the base germplasm until the final evaluation; and Murphy et al. (2005) recommend a specific method for breeding for organic conditions that they call an evolutionary participatory breeding method for improving inbred small grain crop species on a large number of low-input and organic farms.

In the current trials, GE was very important probably due to the variety of environments and cultural practices involved; nevertheless, evaluations of wide collections of maize varieties for human consumption under conventional or organic agriculture show large diversity also for the importance of GE (Duarte et al. 2005; LeFord and Russell 1985; Malvar et al. 2008; Revilla et al. 2008). Other reports combining organic and conventional agriculture have shown inconsistent results concerning GE (Lazcano et al. 2011; Ardelean et al. 2012).

Meiro(P)C2 and some of the commercial checks had the highest flour yield and, although the rank for flour yield was not the same under organic and conventional conditions, there was a reasonable agreement for the best and the worst genotypes. Grain yield was highest for both commercial checks, followed by Meiro(P)C2 and Martikoenea. Milling test was not as discriminating as yield and many varieties were not significantly different from those with hardest grains across conditions. Comparisons of means were more discriminating under organic than under conventional agriculture because the organic fields used here were less heterogeneous than the conventional fields and, thus, GE was higher under conventional agriculture. Rank correlations between organic and conventional conditions were moderate for flour yield, yield, and milling test. Other authors have reported low correlations between organic and conventional conditions (Löschenberger et al. 2008). Burger et al. (2008) reported moderate phenotypic correlations between organic and conventional agriculture for grain yield and strong correlation for grain dry matter content but not consistent genotypic correlations for maize hybrids. Boller et al. (2008) found good correlations between yield of grasses under organic and conventional conditions and Lorenzana and Bernardo (2008) reported that genetic correlations for performance in the two production systems were 0.84 for grain yield; greater than 0.90 for grain moisture, plant height, and ear height; and about 0.50 for root lodging and stay green for maize hybrids.

As the organic and the conventional trials were carried out in different locations we cannot make direct comparisons between organic and conventional conditions. Nevertheless, genotypes performed under organic conditions better than under conventional conditions for early vigor and plant appearance, and had fewer days to silking, while conventional conditions were superior for ears per plant, yield and flour yield, grain moisture (drier grains), 100 grain weight, and grain density; also grains were harder under organic conditions. Burger et al. (2008) found that maize hybrids yielded 16 % less under organic than under conventional conditions. As a general trend, our open-pollinated varieties performed better in the organic environments for vegetative traits and in the conventional environments for yield components. Indeed, these results depend both on the genotypes and locations involved in these experiments.

The earliest varieties, based on flowering and grain moisture, were Sarreaus and its improved cycles, Donostia and its improved cycle, and Martikoenea. The varieties with longest growth cycle had also the highest yield, such as Meiro and its improved cycles and some commercial checks. The correlation between flowering and grain moisture was low, but several varieties performed differently for grain moisture under organic and conventional conditions but there were also some agreements between organic and conventional conditions.

Quality traits varied between organic and conventional conditions, as under organic conditions grains were harder and had lower weight and density. Although quality is important for these populations initially intended for human consumption, it is not clear which are the parameters that define quality. In previous works we have considered that grain weight, milling test, and grain density were important quality factors (Revilla et al. 2008) following a general opinion that considers purity of the white color, large uniform size of grains, high specific density, hard endosperm, and white cob (Watson 1988). Here we include black and yellow varieties because in these regions they are used also for human consumption. The lack of response to selection for quality traits can be partially due to the genetic complexity involved in its regulation (Alonso Ferro et al. 2008; Malvar et al. 2008).

Generally, correlations between traits were higher under organic than under conventional conditions and correlations among traits under organic and conventional conditions were different for a number of pairs of traits, such as grain yield and grain moisture under conventional and organic conditions, which were both significant but with opposite signs, as were for flour yield with grain moisture under conventional and organic conditions. There were also pairs of traits with significant correlation under conventional conditions, but not under organic conditions; the reason for these discrepancies could be that the conventional environments where the trials were carried out were more similar to the environments used for selection than the organic environments. Besides, the relationships between agronomic performance and quality were not strong, except for milling test that had a negative correlation with yield, flour yield, and grain moisture; these correlations were even weaker under organic conditions. In a previous work we also found a weak relationship between yield and quality under organic conditions (Revilla et al. 2008).

As conclusion, breeding has been efficient for Meiro in organic conditions while for the other populations was equally inefficient under organic and conventional conditions. The GE and the complexity of these traits can be partially responsible for these negative results because their improvement is not straightforward.

Acknowledgments Research was supported by the Spanish Plan for Research and Development (project code AGL2010-22254), the Basque Government, and the Diputación Provincial de Pontevedra.

References

Alonso Ferro RC, Malvar RA, Revilla P, Ordás A, Castro P, Moreno-González J (2008) Inheritance of quality and agronomic traits in hard endosperm maize for human food. J Agric Sci 146:551–560

Ardelean M, Cordea M, Haş V, Bors A (2012) G × E Interaction on yield stability of five sweet corn hybrids grown under different agricultural systems. Not Botkert Hort Agrobot 40:290–292

Boller B, Tanner P, Schubiger FX (2008) Breeding forage grasses for organic conditions. Euphytica 163:459–467

Burger H, Schloen M, Schmidt W, Geiger HH (2008) Quantitative genetic studies on breeding maize for adaptation to organic farming. Euphytica 163:501–510

Duarte AP, Mason SC, Jackson DS, Kiehl JC (2005) Grain quality of Brazilian genotypes as influenced by nitrogen level. Crop Sci 45:1958–1964

He H, Hoseney RC (1991) Gas retention at different cereal flours. Cereal Chem 68:334–336

Kovacevic D, Lazic B (2012) Modern trends in the development of agriculture and demands on plant breeding and soil management. Genetika 44:201–216

Landa A, Revilla P, Malvar RA, Butrón A, Ordás A (2006) Maíz para panificación. Agricultura 886:506–509

Lazcano C, Revilla P, Malvar RA, Domínguez J (2011) Yield and fruit quality of four sweet corn hybrids (Zea mays) under conventional and integrated fertilization with vermicompost. J Sci Food Agric 91:1244–1253

Leford DR, Russell WA (1985) Evaluation of physical grain quality in the BS17 and BS1(HS)C1 synthetics of maize. Crop Sci 25:471–476

Lorenzana RE, Bernardo R (2008) Genetic correlation between corn performance in organic and conventional production systems. Crop Sci 48:903–910

Löschenberger F, Fleck A, Grausgruber H, Hetzendorfer H, Hof G, Lafferty J, Marn M, Neumayer A, Pfaffinger G, Birschitzky J (2008) Breeding for organic agriculture: the example of winter wheat in Austria. Euphytica 163:469–480

Malvar RA, Revilla P, Moreno-González J, Butrón A, Sotelo J, Ordás A (2008) White maize: genetics of quality and agronomic performance. Crop Sci 48:1373–1381

Murphy K, Lammer D, Lyon S, Carter B, Jones SS (2005) Breeding for organic and low-input farming systems: an evolutionary–participatory breeding method for inbred cereal grains. Renew Agric Food Syst 20:48–55

Poneleit CG (2001) Breeding white endosperm maize. In: Hallauer AR (ed) Specialty corns, 2nd edn. CRC Press, Boca Raton, pp 235–273

Revilla P, Landa A, Rodríguez VM, Romay MC, Ordás A, Malvar RA (2008) Maize for bread under organic agriculture. SJAR 6:241–247

Revilla P, Landa A, Rodríguez A, Ordas A, Malvar RA (2012) Influence of growing and storage conditions on bakery quality of traditional maize varieties under organic agriculture. Crop Sci 52:593–600

Rodrigues de Oliveira L, Vieira Miranda G, Oliveira DeLima R, Vagno de Souza L, Cardoso Galvão JC, Cristina dos Santos I (2011) Combining ability of tropical maize cultivars in organic and conventional production systems. Ciênc Rural 41:739–745

Rodríguez VM, Soengas P, Landa A, Ordá A, Revilla P (2013) Effects of selection for color intensity on antioxidant activity in maize (*Zea mays* L.). Euphytica 193:339–345

Romay MC, Ordás B, Revilla P, Ordás A (2011) Three cycles of reciprocal recurrent selection in two Spanish maize synthetics. Crop Sci 51:1016–1022

SAS Institute (2010) SAS Version 9.3. The SAS Institute, Cary

Serna-Saldivar SO, Gómez MH, Rooney LW (2001) Food uses of regular and specialty corns and their dry-milled fractions. In: Hallauer AR (ed) specialty corn. CRC Press, Boca Ratón, pp 303–337

Troyer AF (1999) Background of U.S. hybrid maize. Crop Sci 39:601–626

Vales MI, Malvar RA, Revilla P, Ordas A (2001) Recurrent selection for grain yield in two Spanish maize synthetic populations. Crop Sci 41:15–19

Van Bueren ETL, Jones SS, Tamm L, Murphy KM, Myers JR, Leifert C, Messmer MM (2011) The need to breed crop varieties suitable for organic farming, using wheat, tomato and broccoli as examples: a review. Njas-Wagening J Life Sci 58:193–205

Watson SA (1988) Maize marketing, processing, and utilization. In: Sprague GF, Dudley JW (eds) Maize and maize improvement, 3rd edn. American Society Agronomy, Madison, pp 881–940

Weyhrich RA (1998) Responses to seven methods of recurrent selection in the BS11 maize population. Crop Sci 38:308–321

Wolfe MS, Baresel JP, Desclaux D, Goldringer I, Hoad S, Kovacs G, Löschenberger F, Miedaner T, Østergård H, van Bueren ETL (2008) Developments in breeding cereals for organic agriculture. Euphytica 163:323–346