Yield performance of the European Union Maize Landrace Core Collection under multiple corn borer infestations

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Abstract

In Europe, corn borer attack is the main biotic stressor for the maize (*Zea mays* L.) crop. European corn borer (*Ostrinia nubilalis* Hbn.) is the most important maize pest in central and north Europe, while pink stem borer (*Sesamia nonagrioides* Lef.) is predominant in warmer areas of southern Europe. The objective of this study was the evaluation of the European Maize Union Landrace Core Collection (EUMLCC) for yield under infestation with European corn borer (*O. nubilalis*) and pink stem borer (*S. nonagrioides*). Eighty-five landraces from Germany, Spain, France, Greece, Italy, and Portugal were evaluated, under corn borer infestation, for yield, grain moisture, and days to flowering at two locations in Spain. Landraces were evaluated separately in four trials that corresponded to four maturity groups. In each maturity group, there were significant differences among landraces for yield of infested plants. Extra-early landraces, ESP0090214, FRA0410010, and ESP0070339; early landraces, FRA0410022, and ESP11985022; midseason landraces, PRT00100392 and ESP11981047; and late landraces, PRT00100569 and

PRT00100530, were promising sources of high-yielding maize under corn borer infestation and showed relative earliness within their maturity groups.

Sesamia nonagrioides; *Ostrinia nubilalis*; Corn borer; *Zea mays*; Core collection; Germplasm

1. Introduction

Maintaining genetic resources is a priority in a world concerned with the loss of genetic variability. However, as several authors have pointed out (Goodman, 1990; Shands, 1990; Crossa et al., 1994), ex situ genetic resource management should not just pursue the acquisition and storage of accessions, but go further since the final goal is to use the genetic diversity. Therefore, it would be necessary to characterize, regenerate, and evaluate crop accessions before using them in breeding programs (Crossa et al., 1994). Germplasm from a representative subset could be used to facilitate evaluations while maintaining genetic variation. Frankel and Brown (1984) defined a core collection as the small subset of accessions that represents a large part of the diversity found in the entire collection. Forty-five accessions and three accession composites were selected from a total of 848 Tuxpeño accessions and accession composites to form the final core subset of the maize race Tuxpeño (Taba et al., 1992; Crossa et al., 1994). A core subset of the Caribbean maize collection was made by selecting the upper 20% of the accessions (100 in total) which represent the phenotypic diversity and have superior selection indexes based on yield, ear rot, plant erectness, and moisture (Taba et al., 1998). Several European maize breeding groups have a commitment with the European Union to develop the European Union Maize Landrace Core Collection (EUMLCC), evaluate it, and make it available. Several maize landraces from Italy, Germany, France, Greece, Portugal, and Spain have been molecularly, biochemically, and morphologically characterized. A core subset of the total accessions was selected based on those data and breeders' knowledge and will constitute the EUMLCC (Rebourg et al., 2003). Information about those accessions is available at www.montpellier.inra.fr/gap/resgen88/results.htm#database.

The EUMLCC should be an active collection that might be largely used in the future by maize breeders. Therefore, it would be advisable to know the performance of these materials under the stress conditions that could happen in the proposed area. There are two main maize pests in central and southern Europe: *Ostrinia nubilalis* and *Sesamia nonagrioides*. The former pest is present all across Europe, while the presence of *S. nonagrioides* is limited to the Mediterranean area where it is the main biotic constraint for achieving maize yield potential (Anglade, 1972). The two species are corn borers, whose larvae feed on the pith of maize stalks, but they can also be found on the ears (Butrón et al., 1998; Velasco et al., 1999b).

Efforts have been made to look for sources of resistance to corn borer attack among field corn landraces (Anglade, 1961; Anglade and Bertin, 1968; Guthrie and Dicke, 1972; Hudon and Chiang, 1985 and Hudon and Chiang, 1991; Malvar et al., 1993 and Malvar et al., 2004; Cartea et al., 1994; Butrón et al., 1999a) and sweet corn genotypes (Pounders et al., 1975; Andrew and Carlson, 1976; Grier and Davis, 1980; Velasco et al., 1999a and Velasco et al., 1999b). Nevertheless, few studies have been focused on finding sources of tolerance to *S. nonagrioides* (Butrón et al., 1998) and *O. nubilalis* (Anglade et al., 1996). Butrón et al. (1998) found out that only a small part of the variation of yield loss could be predicted from the level of antibiosis against *S. nonagrioides* attack. These findings stressed the importance of selecting genotypes by a comprehensive measurement such as yield loss that combines antibiosis and tolerance. Yield losses, however, could be compensated in part by high potential yield (Lynch, 1980; Butrón et al., 1999b). Therefore, evaluating yield under infestation conditions appears to be the best way to estimate the defense level against insect attack. Selecting for yield under infestation would increase resistance and/or tolerance, depending on the mechanism working against corn borer attack. In addition, it would eliminate the risk of loosing yielding ability after selecting for insect resistance as some authors have reported (Russell et al., 1979; Klenke et al., 1986 and Klenke et al., 1988; Butrón et al., 2000 and Butrón et al., 2002).

This paper complements the information published on the differences among the European maize landraces of the EUMLCC for plant resistance measured as tunnel length in the stem and damage on the grain (Malvar et al., 2004) by evaluating the

EUMLCC for yield under artificial infestation conditions with either *O. nubilalis* or *S. nonagrioides*.

2. Materials and methods

Eighty-five maize landraces (open-pollinated farmer varieties that are no longer cultivated), that represent maize variability in several European countries, were evaluated under artificial infestation with *S. nonagrioides* and *O. nubilalis* eggs (Table 2). Landraces were classified into four maturity groups, according to the growing degree units in their countries of origin, and each maturity group was evaluated separately, although checks were the same (hybrids Antares, Costanza, and DK-485). A split-plot design was used to evaluate landraces within each germplasm group. Species of insects (*S. nonagrioides* or *O. nubilalis*) were assigned to main plots and landraces to subplots. In the *O. nubilalis* and late variety groups, landrace subplots were sorted in three completely random blocks. Early variety subplots were arranged in a triple lattice 6×6, while midseason variety subplots were arranged in a triple lattice 5×6. Each experimental subplot consisted of two rows with 25 two-kernel hills. Rows were spaced 0.80 m apart and hills in the row were spaced 0.21 m apart. After thinning, the final density was approximately 60,000 plants ha^{-1}.

Evaluations were made at two locations, Pontevedra and Zaragoza, in 2001. The places used for testing are both in Spain but their climatic conditions are totally different. *S. nonagrioides* is the most abundant corn borer in Pontevedra, while European corn borer is predominant in Zaragoza (Malvar et al., 1993; Cordero et al., 1998). However, artificial infestations with both borers were made at both locations. Zaragoza (41° 44′N, 0° 47′W) is an inland location characterized by very cold winters and warm summers, while Pontevedra (42° 30′N, 8° 46′W) is on the Atlantic coast and temperatures are mild all year around. Therefore, Zaragoza has a continental climate and Pontevedra has a climate with some Mediterranean characteristics. In addition, ecological considerations were taken into account for selecting those locations, because evaluations were made under infestation with two borer species and we did not want to spread any of them in areas where they are not naturally present (in northern and central Europe *S. nonagrioides* is not present). Under infestation conditions, in general, non-significant year×genotype interactions were previously found for any damage trait (Butrón et al., 1999a and Butrón et al., 1998; Velasco et al., 1999b). As significant year×genotype interactions were not expected and the insect rearing and infestations consume time, work, and cost, the evaluation was only made in one growing season. Besides, materials evaluated are not breeding populations but landraces and this work constitutes a preliminary study on the abilities of these populations for being used for breeding purposes, and to discard those populations with very poor agronomic characteristics.

O. nubilalis and *S. nonagrioides* were infested as eggs during silking stage of corn. Ten plants per subplot received a mass of about 40 eggs of either *S. nonagrioides* or *O. nubilalis*, depending on the main plot. The infestation was made according to Butrón et al. (1998): eggs were placed between the shank of main ear and the stem. The rearing method of *S. nonagrioides* has been described by Eizaguirre (1989). The *O. nubilalis* eggs were supplied by the Centre de Recherches de Poitou-Charentes (Institute National de la Recherche Agronomique, France).

In each subplot, number of days to silking (from sowing to 50% plants silking) and percentage of grain moisture at harvest were recorded. Yield of infested plants at 140 g kg^{-1} moisture content was calculated from the ears of infested plants.

Individual and combined analyses of variance over locations were calculated for yield of infested plants, grain moisture, and days to silking. Locations and replications were considered as random factors and landraces and species of insect as fixed factors. Comparisons of means were carried out by the least significant difference (LSD) method. All analyses were made using the SAS software (SAS Institute, 2000).

3. Results and discussion

There were not significant differences between species of insect for yield of infested plants, and the insect species×variety interaction was non-significant for any maturity group (Table 1), so performance of maize varieties under infestation by *S. nonagrioides* and *O. nubilalis* was similar. Velasco et al. (1999b) had already pointed out that resistance to both corn borers is not completely independent.

Table 1.

Mean squares of the analysis of variance of the EUMLCC for three traits evaluated under corn borer infestation with *S. nonagrioides* and *O. nubilalis* in 2001

Source of variation	df	Yield	Grain moisture	Days to silking
Extra-early				
Location (L)	1	46.93	2787.60*	414.82*
Insect (I)	1	5.30	43.57	63.56
L×I	1	7.64	22.92*	6.82
Replication (L×I)	8	2.23**	4.30	6.94**
Variety (V)	12	12.06**	167.79**	747.79**
L×V	10	1.32	9.50**	10.93
I×V	12	0.48	5.77*	5.89
L×I×V	10	0.88	1.71	6.53**
Error	87	0.55	2.30	2.48
Early				
Location (L)	1	154.62	4892.21*	476.10
Insect (I)	1	0.04	124.52	6.05
L×I	1	15.35**	35.78	16.04
Replication (L×I)	8	0.46	8.15**	8.10**
Variety (V)	32	11.94**	47.92**	59.50**
L×V	29	3.46**	14.90**	5.48**
I×V	32	0.54	2.80	1.93
L×I×V	29	1.02**	3.04	2.24
Error	244	0.50	3.12	1.57
Midseason				
Location (L)	1	202.90*	7914.80**	1465.57**
Insect (I)	1	0.62	37.02	13.74
L×I	1	4.01	5.86	5.80
Replication (L×I)	8	1.71	3.45*	5.30**
Variety (V)	26	8.64**	30.35**	79.44**
L×V	22	3.17	7.42**	19.38
I×V	26	0.93	1.59	12.32

Source of variation	df	Yield	Grain moisture	Days to silking
L×I×V	22	1.65	1.53	14.63**
Error	192	1.18	1.62	1.52
Late				
Location (L)	1	0.86	1563.45**	534.02**
Insect (I)	1	0.09	11.18	2.87**
L×I	1	0.34	6.25	0.42
Replication (L×I)	8	0.84	5.53	6.76
Variety (V)	11	31.47**	64.01	127.30
L×V	4	0.91	13.24	39.60*
I×V	11	1.32	3.87	2.87
L×I×V	4	0.95	5.55	3.67
Error	59	1.89	3.75	3.23

*,** Significant at the 5% and 1% level of probability, respectively.

Within the group of early landraces, there were significant interactions between landraces and locations and between landraces, locations, and insects for yield of infested plants (Table 1). Individual analysis of variance of early landraces for yield of infested plants showed that the species of insect×variety interaction was significant in Zaragoza, while it was not significant in Pontevedra (data not shown). Nevertheless, in Zaragoza, landraces that had a good performance under *O. nubilalis* attack were among the most productive under infestation with *S. nonagrioides*, excepting the variety PRT00100186 (data not shown). Besides, the location×variety interaction for yield of infested plants appeared to be mostly due to magnitude changes rather than to changes in rank. For grain moisture, and days to silking, there were significant differences among extra-early, early, and midseason landraces, although some interactions with landraces were significant for those traits.

Among the extra-early landraces, DEU1460239, GRC0010085, ESP0090214 (named ‘Viana’), FRA0410010, and ESP0070339 stood out for being significantly more productive than the remaining landraces under artificial infestation (Table 2). However, DEU1460239 showed high grain moisture at harvest (25%) and GRC0010085 flowered even later than the latest check (Costanza). Some mistake classifying landraces into maturity groups, according to the growing degree units in their countries of origin, should be responsible for the inclusion of GRC0010085 in the extra-early group because it flowered as late as landraces included in the late trial. Viana had already performed well under natural infestation in a previous study (Malvar et al., 1993). The Landrace DEU140023 had a very bad performance because it yielded 0.54 mg ha^{-1}. Therefore, removal from the EUMLCC should be considered.

Table 2.

Kernel characteristics, days to silking, grain moisture, and yield under infestation with *S. nonagrioides* and *O. nubilalis* of the EUMLCC evaluated at two locations in 2001

Accession number[a]	**Kernel type**	**Kernel color**	**Days to silking (No.)**	**Grain moisture (%)**	**Yield of infested plants (Mg ha^{-1})**
Extra-early					
DEU1460023	Flint	Yellow	51	19.5	0.54
DEU1460239	Flint	Yellow	59	25.2	5.12
ESP0070339	Flint	Yellow	57	19.9	4.03
ESP0090214	Flint	Yellow	54	20.8	4.27
ESP0090300	Semi-flint	Orange	50	21.1	1.90
FRA0410010	Flint	Yellow	53	19.6	4.09
FRA0410031	Flint	Yellow	58	20.2	2.92
FRA0410969	Flint	Orange	54	18.6	3.02
GRC0010085	Semi-flint	White	82	32.6	4.70
PRT00100088	Flint	Yellow	53	18.3	2.78
PRT00100867	Flint	Yellow	60	21.1	3.38
PRT00100813	Flint	Yellow	53	21.2	2.79
PRT00100916	Flint	Yellow	56	21.5	2.94

Accession number[a]	**Kernel type**	**Kernel color**	**Days to silking (No.)**	**Grain moisture (%)**	**Yield of infested plants (Mg ha^{-1})**
LSD (5%)			3	3.1	1.14
Antares			59	18.9	8.00
Costanza			76	31.7	14.74
DK-485			72	25.1	11.38
Early					
DEU1460158	Flint	Yellow	59	25.0	3.31
DEU1460312	Flint	Yellow	61	20.6	2.63
ESP0070127	Flint	Brown	60	19.0	3.19
ESP0070217	Flint	Orange	65	22.2	4.85
ESP0070892	Flint	Orange	63	21.6	4.82
ESP0090205	Flint	Yellow	66	23.7	6.67
ESP11981040	Flint	White	63	21.9	4.88
ESP11982019	Flint	Yellow	61	19.8	4.76
ESP11982031	Flint	Yellow	64	22.4	5.86
ESP11985022	Flint	Yellow	60	19.7	5.72
FRA0410006	Flint	Yellow	60	18.8	4.50
FRA0410015	Flint	Yellow	60	20.6	4.11
FRA0410022	Flint	Yellow	59	19.9	5.24
FRA0410023	Flint	Yellow	59	20.0	4.01
FRA0410090	Flint	Brown	65	24.1	6.12
FRA0410474	Flint	White	62	21.2	4.38
GRC0010016	Semi-flint	Yellow	67	25.2	4.24
GRC0010017	Flint	Yellow	66	23.5	3.95
GRC0010051	Flint	Orange	62	22.6	4.79
GRC0010084	Flint	Yellow	66	24.2	6.33
GRC0010160	Flint	Yellow	61	22.0	4.47

Accession number[a]	**Kernel type**	**Kernel color**	**Days to silking (No.)**	**Grain moisture (%)**	**Yield of infested plants (Mg ha^{-1})**
GRC0010172	Semi-dent	White	64	23.7	4.15
GRC0010179	Flint	Orange	60	21.5	2.45
ITA0370071	Semi-flint	Orange	60	24.5	4.78
ITA0370154	Flint	Orange	64	23.5	4.51
PRT00100019	Flint	Yellow	65	26.0	4.52
PRT00100049	Flint	Yellow	66	22.9	4.68
PRT00100120	Flint	Yellow	61	20.8	4.55
PRT00100186	Flint	Yellow	63	20.8	5.24
PRT00100291	Flint	White	63	18.3	5.05
PRT00100394	Flint	Yellow	62	21.1	5.14
PRT00100815	Flint	Yellow	61	24.1	4.33
PRT00100828	Flint	Yellow	63	17.6	2.68
LSD (5%)			2	3.4	1.62
Antares			60	18.9	7.61
Costanza			77	32.3	14.46
genbank:DK-465			71	23.6	9.38
Midseason					
ESP0070784	Flint	Yellow	68	23.1	5.48
ESP0090025	Dent	Yellow	66	21.7	4.26
ESP0090033	Semi-dent	Yellow	66	20.9	5.23
ESP0090067	Flint	Yellow	71	20.3	4.64
ESP0090343	Dent	Yellow	71	25.5	4.95
ESP11973C03	Dent	Yellow	68	20.9	6.16
ESP11981047	Semi-Dent	Yellow	64	20.7	5.51
ESP11982012	Flint	Yellow	65	22.2	5.61

Accession number[a]	Kernel type	Kernel color	Days to silking (No.)	Grain moisture (%)	Yield of infested plants (Mg ha^{-1})
ESP11985020	Flint	White	65	22.2	6.66
FRA0410194	Semi-flint	Yellow	66	22.6	6.68
FRA0410496	Flint	White	71	20.1	4.74
FRA0410619	Flint	Yellow	66	20.4	4.96
FRA0410625	Flint	Yellow	73	21.1	4.77
FRA0410636	Flint	White	73	20.1	3.37
FRA0410639	Flint	White	69	21.9	5.96
FRA0410668	Flint	White	69	22.1	5.39
GRC0010012	Flint	Yellow	70	21.9	5.33
GRC0010165	Semi-dent	Yellow	68	24.9	4.96
GRC0010174	Semi-dent	White	65	22.7	5.67
GRC0010183	Flint	White	67	21.5	4.36
ITA0370058	Semi-flint	Yellow	65	23.1	6.41
ITA0370143	Semi-flint	Red	63	24.2	5.98
ITA0370185	Dent	White	67	29.1	9.05
ITA0370488	Semi-flint	Orange	65	24.6	5.77
PRT00100392	Flint	White	63	20.3	6.17
PRT00101526	Flint	White	65	18.8	4.18
PRT00102047	Flint	White	70	21.5	5.67
LSD (5%)			4	2.5	1.61
Antares			60	18.0	7.82
Costanza			77	26.7	13.52
DK-485			71	20.8	10.29

Accession number[a]	**Kernel type**	**Kernel color**	**Days to silking (No.)**	**Grain moisture (%)**	**Yield of infested plants (Mg ha^{-1})**
Late					
DEU1460013	Dent	Yellow	68	29.1	2.64
ESP0070441	Pop	Purple	82	24.3	3.27
ESP0090032	Dent	Yellow	71	23.6	6.30
ESP0090315	Semi-dent	White	78	24.6	4.48
ITA0370005	Flint	Orange	70	27.8	6.68
ITA0370026	Dent	White	69	29.7	6.51
ITA0370088	Dent	Yellow	69	31.9	4.53
ITA0370100	Flint	White	72	33.2	7.34
ITA0370171	Dent	Yellow	72	32.5	8.67
ITA0370195	Semi-floury	Yellow	70	30.3	5.34
PRT00100530	Flint	Orange	78	29.5	7.58
PRT00100569	Flint	Yellow	80	31.3	8.17
LSD (5%)					1.36
Antares			60	18.2	7.32
Costanza			78	26.5	12.26
DK-485			71	20.9	9.53

[a] The first three letters stand for the country of origin (DEU for Germany, ESP for Spain, FRA for France, GRC for Greece, ITA for Italy, and PRT for Portugal).

Among the early landraces, ESP0090205, GRC00110084, FRA0410090, ESP11982031, ESP11985022, FRA0410022, FRA0410022, PRT00100186, and PRT00100394 had the greatest yields under infestation conditions. However, as we previously mentioned, PRT00100186 had poor yielding ability under artificial infestation with *S. nonagrioides* eggs in Zaragoza. ESP0090205 (named ‘Tuy’) was previously tested under natural infestation and was among the most productive landraces (Ordás et al., 1988; Malvar et al., 1993). FRA0410022 and ESP11985022, besides being productive under infestation conditions, were very early. Landraces GRC0010084, FRA0410090, and ESP0090205, however, presented days to flowering and grain moisture at harvest significantly higher than FRA0410022 and ESP11985022. Therefore, landraces as FRA0410022 and ESP11985022 could be used for developing early materials, while GRC0010084, FRA0410090, and ESP0090205 could be the base materials for growing areas with longer growing season.

The variety ITA0370185 was the highest yielding among the midseason landraces. However, Italian landraces were only evaluated in one environment (Pontevedra) because not enough seed was available to perform two trials. Therefore, it is necessary to evaluate those landraces in at least on other environment to have more reliable data about their performance under corn borer infestation. Besides, in Pontevedra, other midseason varieties such as ESP11985020, PRT00100392, FRA0410194, ESP11973C03, and PRT00102047 did not significantly differ from the Italian landrace ITA03700185 (data not shown). In the midseason group, among landraces evaluated in two environments, FRA0410194, ESP11985020, PRT00100392, ESP11973C03, FRA0410639, GRC0010174, PRT00102047, ESP11982012, ESP11981047, ESP0070784, FRA0410668, GRC0010012, and ESP0090033 were significantly more productive under corn borer infestations. Landraces PRT00100392 and ESP11981047 showed less grain moisture and days to silking than others. The population ESP0090033 (named ‘Tremesino’) had been already cited as a promising source of yielding ability under corn borer infestation because it had favorable variety effects for yield under infestation with *S. nonagrioides* in a previous study (Soengas et al., 2004).

In the late group, landraces ITA0370171, PRT00100569, PRT00100530, and ITA0370100 performed better than others under corn borer infestation conditions. However, Italian landraces, as we have already said, were tested in one environment only. The variety ESP0090032 (named ‘Rastrojero’), that in previous studies was among the most resistant and productive populations under corn borer natural infestation conditions (Ordás et al., 1988; Malvar et al., 1993), performed significantly worse than PRT00100569 under artificial infestation conditions. Therefore, this work was able to find materials even more suitable to use in breeding programs to decrease corn borer attack impact than the ones that we already had. It would be necessary to study the heterosis among these promising populations, to know the real potential of these populations for generating inbred lines that in hybrid combination will render productive hybrids under corn borer infestations. A study on heterosis patterns among French and Spanish populations reported that populations Lazcano, from northern Spain, and Millete de Lauragais, from southern France, would be appropriate for developing inbred lines with high heterosis effects when crossed (Malvar et al., 2004). Millete de Lauragais is a midseason population (FRA0410639) that had good performance under corn borer infestation.

In general, the most productive landraces under artificial infestation with corn borers came from southern Europe, as expected, because they should be adapted to the high natural infestation, mainly by *S. nonagrioides*, that is a common pest of maize in that region. In general, the most productive landraces under corn borer infestation had their origin in areas with mild temperatures all throughout the year. In contrast, in Germany, northern France, or Central Spain where cold winter temperatures limit corn borer development, few populations were reported with high yield under infestation conditions. Ordás et al. (1988) found out that US Corn Belt populations were less resistant than Spanish populations since *O. nubilalis* is a recent pest in USA and *S. nonagrioides* is not present in that country.

In conclusion, yield under infestation conditions, as an indicator of the level of defense against corn borer attack, of 85 maize landraces was evaluated and the most promising sources could be used in breeding programs. Extra-early landraces, ESP0090214, FRA0410010, and ESP0070339; early landraces, FRA0410022 and ESP11985022; midseason landraces, PRT00100392 and ESP11981047; and late landraces, PRT00100569 and PRT00100530, were the most promising sources of high yields under artificial infestation with corn borer eggs and showed relative earliness. Crosses among the inbred lines developed from these populations will follow the heterotic pattern 'flint×flint' that could be a good alternative to the most common hybrids used in Europe, 'European flint×American dent', mostly in regions where earliness is required.

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