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EUROPEAN CORN BORER RESISTANCE IN SORGHUM COMPARED WITH MAIZE

Iowa State University PH.D. 1983

University
Microfilms
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European corn borer resistance in sorghum

compared with maize

by

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A Dissertation Submitted to the

Graduate Faculty in Partial Fulfillment of the

Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Major: Entomology

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

For the Graduate College

Iowa State University
Ames, Iowa

1983

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GENERAL INTRODUCTION

The European corn borer (ECB), *Ostrinia nubilalis* Hübner, occurs in several countries in Africa, Europe, and Asia (Ortega et al., 1980) and was first discovered in the United States in 1916 (Smith, 1920). At present, the ECB is found in most states east of the Rocky Mountains, in several Canadian Provinces, including Prince Edward Island, and has one to four generations/year (Showers, 1979; Thompson and White, 1977).

Although the ECB can complete its life cycle on many species of plants in North America, maize, *Zea mays* L., is its preferred host (Hodgson, 1928; Dicke, 1932). This exotic species has become one of the most destructive insect pests of maize throughout the Maize Belt of the United States. On maize plants, 1st-generation ECB larvae cause damage primarily to leaf tissue; as plants grow out of the whorl stage, the larvae invade sheaths, collars, and stalks, but most larvae pupate before much stalk damage occurs. Over 95% larval mortality occurs within 5 days after egg hatch on resistant genotypes of maize; this is a high degree of antibiosis against 1st- and 2nd-instar larvae (Guthrie et al., 1960).

A vast amount of information is available on resistance in maize to leaf feeding by 1st-generation ECBs. Resistant germplasm has been easy to locate (Guthrie and Dicke, 1972). Resistance is polygenic; at least 6 genes are involved (Scott et al., 1966). The type of gene action is primarily additive (Scott et al., 1964).

Little research has been conducted on resistance in sorghum, *Sorghum bicolor* (L.), to leaf feeding by 1st-generation borers. Painter and Weibel (1951) found that newly hatched larvae of the 1st-generation feed to some extent in the whorl resulting in small lesions on a few leaves, similar to the early leaf injury in maize, and most larvae do not develop beyond the 5th instar. During the 1960s, F. F. Dicke, Pioneer Hi-Bred International Inc., (unpublished data) found that several varieties of sorghum were resistant to leaf feeding by 1st-generation borers.

During the period of egg deposition by 2nd-generation ECBs in the Maize Belt States, maize is in various stages of anthesis. The initial establishment by 1st-instar larvae is primarily on sheath and collar tissue (Guthrie et al., 1970). Resistance to sheath-collar feeding in maize by 2nd-generation ECBs is polygenic; at least 7 genes are involved (Onukogu et al., 1978), and the type of gene action is primarily additive, although resistance is partially dominant (Jennings et al., 1974a, 1974b). In maize, most larval mortality occurs within 3 days after egg hatch; a high level of antibiosis against 1st- and 2nd-instar larvae (Guthrie et al., 1970).

Infestations in sorghum by the ECB have been reported by several investigators in several countries (Caffrey and Worthley, 1927; Hodgson, 1928; Huber et al., 1928; Thompson and Parker, 1928; Babcock and Vance, 1929; Dicke, 1932; Clark, 1934; and Hsu, 1936); these infestations probably occurred during anthesis.

Dicke et al. (1963) evaluated several varieties of sorghum for resistance to 2nd-generation ECBs. Artificial infestations were made during anthesis. In general, the kafir and feterita varieties were low in number of sheath lesions, cavities, and larvae. The kaoliang types were low to moderate. The durra, shrock, and hegari varieties were moderately heavy to heavy, and the milo types were among the more heavily infested varieties.

The genetics of resistance to 2nd-generation ECBs in sorghum is not known, but several genes are probably involved. Progress has been made in breeding for resistance in sorghum with recurrent selection in S_1 lines from two random-mating populations (Atkins et al., 1983).

The parents of sorghum hybrids are inbred lines (before the use of hybrids - widely grown varieties), but, unlike maize inbreds, are vigorous. The objectives of my research were (1) to evaluate a large number of sorghum hybrids for resistance to leaf feeding by 1st-generation ECB larvae under very heavy infestation conditions, (2) to determine the rate of 1st-generation larval mortality in four sorghum hybrids compared with two inbred lines of dent maize, and to determine 1st-generation larval feeding sites on sorghum, (3) to determine survival and development of ECB larvae reared on meridic diets containing leaves of four sorghum hybrids compared with meridic diets containing leaves of two highly resistant and two susceptible genotypes of dent maize, and (4) to determine the rate of 2nd-generation larval mortality in four sorghum hybrids compared with three inbred lines of dent maize, and to determine 2nd-generation larval feeding sites in sorghum.

EXPERIMENT I. RESISTANCE OF 211 SORGHUM GENOTYPES TO LEAF FEEDING BY FIRST-GENERATION EUROPEAN CORN BORER LARVAE COMPARED WITH FIVE MAIZE GENOTYPES

INTRODUCTION

The European corn borer (ECB), Ostrinia nubilalis Hübner, occurs in several countries in Africa, Europe, and Asia (Ortega et al., 1980) and was first discovered in the United States (Everett, MA) in 1916 (Smith, 1920). At present, the ECB is found in most states east of the Rocky Mountains, in several Canadian Provinces, including Prince Edward Island, and has one to four generations/year (Showers, 1979; Thompson and White, 1977).

Although the ECB can complete its life cycle on many species of plants in North America, maize, zea mays L., is its preferred host (Hodgson, 1928; Dicke, 1932). This exotic species has become one of the most destructive insect pests of maize throughout the Maize Belt of the United States. On maize plants, 1st-generation ECB larvae cause damage primarily to leaf tissue; as plants grow out of the whorl stage, the larvae invade sheaths, collars, and stalks, but most larvae pupate before much stalk damage occurs. Resistance to 1st-generation borers is, therefore, leaf feeding resistance. Over 95% larval mortality occurs within 5 days after egg hatch on resistant genotypes of maize; this is a high degree of antibiosis against 1st- and 2nd-instar larvae (Guthrie et al., 1960).

A vast amount of information is available on resistance in maize to leaf feeding by 1st-generation ECBs. Resistant germplasm has been easy to locate (Guthrie and Dicke, 1972). Resistance is polygenic; at least 6 genes are involved (short arms of chromosomes 1, 2, and 4 and long arms of chromosomes 4, 6, and 8; Scott et al., 1966). The type of gene action is primarily additive (Scott et al., 1964). Thus, a recurrent selection (utilizing S_1 progeny in random-mating populations) breeding technique is used in developing genotypes of maize resistant to leaf feeding by 1st-generation ECBs.

Infestations in sorghum, Sorghum bicolor (L.), by the ECB have been reported by Caffrey and Worthley (1927), Hodgson (1928), Babcock and Vance (1929), Dicke (1932), Clark (1934), and Hsu (1936). These researchers did not indicate if the infestations occurred during the whorl stage of plant development or at anthesis. A photograph in one of the publications (Caffrey and Worthley, 1927) indicates that the infestations occurred at anthesis.

Very little research has been conducted on resistance in sorghum to leaf feeding by 1st-generation borers. Painter and Weibel (1951) found that newly hatched larvae of the 1st generation feed to some extent in the whorl, resulting in small lesions on a few leaves, similar to the early leaf injury on maize, and most larvae do not develop beyond the 5th instar. Beck and Lilly (1949) found sorghum to be resistant. During the 1960s, F. F. Dicke, Pioneer Hi-Bred International Inc. (unpublished data) evaluated several varieties of sorghum for resistance to 1st-generation borers; ten plants in each plot were infested with three egg masses (ca. 75 eggs)/plant during the midwhorl stage of plant development. All varieties were resistant to leaf feeding.

The parents of sorghum hybrids are inbred lines (before the use of hybrids - widely grown varieties), but, unlike maize inbreds, are vigorous. The objective of our study was to evaluate a large number of sorghum hybrids for resistance to leaf feeding by 1st-generation ECB larvae under very heavy infestation conditions.

MATERIALS AND METHODS

A total of 211 sorghum genotypes (mostly grain type hybrids) and five genotypes of maize (checks) were planted in single row plots (randomized block experimental design with three replications) in 1981 (planted May 15), 1982 (planted June 2), and 1983 (planted May 24). The rows were 3.3 meters long and the distance between rows was 100 cm; stands were thinned to ca. 10 cm between plants when plants were ca. 15 cm high.

Ten plants in each plot were artificially infested with 30 egg masses (ca. 750 eggs)/plant in five applications of six masses each spaced 1 day apart during the midwhorl stage of plant development. Moths originating from larvae reared on a meridic diet for 14 generations were used for egg production. Infestation and egg production techniques were reported by Guthrie et al. (1960, 1971).

Leaf feeding damage was rated (on a plot basis) 21 days after egg hatch as described by Guthrie et al. (1960). In a 1 to 9 rating scale, classes 1-2 are highly resistant, classes 3-4 are resistant, classes 5-6 are intermediate in resistance, and classes 7-9 are susceptible. Plot mean values were used for analysis of variance.

RESULTS AND DISCUSSION

Table 2 shows that the heavy artificial infestation (ca. 750 eggs/plant/season) caused high leaf feeding damage on the two susceptible inbred lines of maize (B73 and WF9) and on the maize single-cross hybrid (M14 X WF9). The resistant inbred lines of maize (B75 and B85) had very little leaf feeding damage. All sorghum hybrids (most were grain types, a few were forage or sorghum sudangrass) were highly resistant (classes 1-2) or were resistant (classes 3-4). There were significant differences between some of the sorghum hybrids (Tables 1 and 2). There were also significant differences between some of the sorghum hybrids compared with the two resistant maize inbred lines (Tables 1 and 2). The differences, however, were probably of little value from a practical point of view.

The data in Table 2 are the first study of whorl stage sorghum under heavy artificial infestation conditions, and confirm results on whorl stage sorghum from a natural infestation reported by Painter and Weibel (1951) and from a low level of artificial infestation (F. F. Dicke, Pioneer Hi-Bred International Inc., unpublished data) i.e., ECB larvae establish at a low level on whorl stage sorghum. The leaves on the sorghum hybrids had pin holes, similar to those on resistant genotypes of maize, but had no elongated lesions indicating that some larvae lived for a short time on leaf tissue.

During some seasons, pin hole type injury occurs in sorghum fields from natural infestations. Extension Entomologists may be tempted, but should not advise farmers to use an insecticide on these fields because the leaf damage seems insufficient to cause economic yield losses.

Table 1. Analysis of variance for data in Table 2. Experiment I. Ankeny, Iowa

Source of variation	Degrees of freedom	1981 Mean square	1981 F	1982 Mean square	1982 F	1983 Mean square	1983 F
Reps.	2	0.5634		1.2692		0.6300	
Genotypes	212	0.0204	1.32**	1.0625	1.62**	0.1650	1.27*
Error	426	0.0155		0.6560		0.1300	

* Significant at the 5 percent probability level.

** Significant at the 1 percent probability level.

Table 2. Leaf feeding ratings in 211 sorghum genotypes compared with five maize genotypes. Experiment I. Ankeny, Iowa

Sorghum genotypes from	Leaf feeding ratings[a]			
	1981	1982	1983	Mean
Texas A&M University				
(ATx378)x(RTx430)	2.0	3.0	2.0	2.3
(ATx399)x(RTx430)	2.0	3.3	2.3	2.5
(ATx2752)x(RTx430)	2.0	3.3	2.0	2.4
RS610	2.0	4.0	2.0	2.7
RS671	2.0	3.0	2.0	2.3
(ATx618)x(RTAM428)	2.0	2.3	2.0	2.1
(ATx615)x(Combine Shallu)	2.0	4.0	3.0	3.0
(ATx623)x(RTx430)	2.0	4.0	2.3	2.8
(ATx623)x(RTAM428)	2.0	3.7	3.3	3.0
(ATx378)x(RTAM428)	2.0	3.3	2.0	2.4
(ATx622)x(SC0056-14)	2.0	3.7	2.0	2.6
(ATx623)x(77CS3)	2.0	3.7	2.0	2.6
(ATx378)x(77CS2)	2.3	4.0	2.3	2.9
(ATx378)x(77CS1)	2.0	3.3	2.0	2.4
(ATx378)x(RTx7078)	2.0	3.7	2.0	2.6
(ATx622)x(RTx7078)	2.0	3.3	2.3	2.5
(ATx622)x(RTx2536)	2.0	4.0	2.3	2.8
(ATx3197)x(RTx2536)	2.0	3.3	2.0	2.4
(ATx622)x(RTx09)	2.3	3.7	2.3	2.8
(ATx623)x(SC0599-11E)	2.0	3.3	2.0	2.4
(ATx623)x(Rio)	2.3	2.7	2.0	2.3
(ATx623)x(CS3541)	2.0	3.0	2.0	2.3
(ATx399)x(75CS5388)	2.0	2.7	2.0	2.2
(ATx378)x(RTx7000)	2.0	2.7	2.0	2.2
(A Atlass)x(RTx430)	2.0	2.7	2.0	2.2
Spur Feterita	2.0	3.7	2.0	2.6
Red Feterita	2.0	3.0	2.0	2.3
Dwarf yellow milo	2.0	4.0	2.7	2.9
SA7088[b]	2.0	3.0	2.0	2.3
Atlas	2.0	3.0	2.0	2.3
Texas Blackhull Kafir	2.0	3.0	2.0	2.3

[a] Three replications each year were rated in classes 1-9 (1 = no damage, 9 = extensive damage to leaf tissue).

[b] Chinchbug resistant milo.

Table 2 (continued)

Sorghum genotypes from	Leaf feeding ratings 1981	1982	1983	Mean
Red Kafir	2.0	3.0	2.0	2.3
White Kafir	2.0	3.7	2.0	2.6
Hegari	2.0	3.0	2.0	2.3
Combine sagrain	2.0	3.0	2.0	2.3
Darso	2.0	4.0	2.0	2.7
Orange	2.3	3.3	2.0	2.5
Sugar drip	2.0	2.7	2.0	2.2
Sourless	2.0	3.3	2.0	2.4
Rio	2.0	2.7	2.0	2.2
Northrup King Co.				
MM54BR	1.7	1.7	2.0	1.8
NK1210	2.3	1.7	2.0	2.0
NK121A	2.0	2.0	2.0	2.0
NK180	2.3	2.0	2.0	2.1
NK129	2.0	2.3	2.0	2.1
NK1580	2.0	2.7	2.0	2.2
NK222	2.0	2.0	2.3	2.1
NK2018	2.0	2.3	2.0	2.1
NK2778	2.0	2.7	2.3	2.3
NK2670	2.0	3.0	2.3	2.4
Savanna 5	2.0	2.3	2.0	2.1
NK2189	2.0	3.3	2.0	2.4
NK2030	2.0	2.3	2.0	2.1
NK2222	2.0	2.7	2.0	2.2
NK2233	2.0	2.3	2.0	2.1
NK233	2.0	2.7	2.0	2.2
NK266	2.0	2.3	2.0	2.1
NK265	2.0	2.7	2.0	2.2
NK2779	2.0	3.0	2.0	2.3
NK280	2.0	3.0	2.0	2.3
Taylor - Evans Seed Co.				
T-E Y101	2.0	2.7	2.3	2.3
T-E Y101R	2.0	3.7	2.3	2.7
T-E Y101D	2.0	3.3	2.0	2.4
T-E FOT AL-D	2.0	2.3	2.0	2.1
T-E Grain Master R	2.0	2.0	2.3	2.1
T-E 66B	2.0	2.7	2.3	2.3
T-E Dinero	2.0	3.0	2.7	2.6
T-E 88H	2.0	2.0	2.0	2.0
T-E Dinero-R	2.0	2.7	2.0	2.2

Table 2 (continued)

Sorghum genotypes from	Leaf feeding ratings 1981	1982	1983	Mean
T-E 66R	2.0	2.7	2.0	2.2
T-E Champ	2.0	3.7	2.0	2.6
T-E Hondo	2.0	2.7	2.0	2.2
T-E Bird-A-BOO	2.0	2.7	2.0	2.2
T-Y-44-R	2.0	2.0	2.0	2.0
T-E-Y-111	2.0	2.3	2.3	2.2
T-E Y-45	2.0	3.7	2.0	2.6
T-E 66	2.0	3.7	2.0	2.6
T-E Tot AL-R	2.0	3.0	2.7	2.6
T-E 77R	2.0	2.7	2.0	2.2
T-E 77A	2.0	2.3	2.3	2.2
NC + Hybrids				
NC + 55x	2.0	2.7	2.0	2.2
NC + 160	2.0	3.0	2.3	2.4
NC + 161	2.0	3.0	2.3	2.4
NC + 168	2.0	3.0	2.0	2.3
NC + 171	2.0	4.0	2.3	2.8
NC + 170	2.0	3.7	2.3	2.7
NC + 172	2.0	3.7	2.3	2.7
NC + 174	2.0	3.0	2.3	2.4
NC + 175[c]	2.0	2.7	2.3	2.3
NC + 271	2.0	2.7	2.3	2.3
NC + 932[d]	2.0	3.0	2.0	2.3
NB + 305F[d]	2.0	3.0	2.0	2.3
NC + 8015[e]	2.0	2.0	2.0	2.0
NC + 856[e]	2.0	2.3	2.0	2.1
NC + 860[e]	2.0	2.7	2.0	2.2
NB + 2805[e]	2.0	2.0	2.7	2.2
NC + 850[e]	2.0	2.7	2.3	2.3

[c] Bird resistant.

[d] Forage type sorghum.

[e] Sorghum-Sudan grass.

Table 2 (continued)

Sorghum genotypes from	Leaf feeding ratings			
	1981	1982	1983	Mean
DeKalb AgResearch, Inc.				
DeKalb 4-25A	2.0	2.0	2.0	2.0
DeKalb A-28+	2.0	2.3	2.0	2.1
DeKalb B-35	2.0	2.0	2.3	2.1
DeKalb BR-38+	2.0	2.3	2.0	2.1
DeKalb BR-38	2.0	2.0	2.0	2.0
DeKalb B-39Y+	2.0	2.3	2.0	2.1
DeKalb C-42A+	2.0	3.0	2.3	2.4
DeKalb C-42Y+	2.0	3.3	2.0	2.4
DeKalb C-43Y+	2.0	3.0	2.0	2.3
DeKalb C-46+	2.0	3.7	2.0	2.6
D-429	2.0	3.3	2.3	2.5
D-42Y+	2.0	2.0	2.7	2.2
D-55+	2.0	2.0	2.0	2.0
DD-50+	2.0	3.3	2.0	2.4
DK-42Y	2.0	3.0	2.0	2.3
DK-54	2.0	2.3	2.0	2.1
DK-57	2.0	2.3	2.0	2.1
DK-59	2.0	3.0	2.0	2.3
DK-61	2.0	3.0	2.3	2.4
DK-64	2.0	2.7	2.3	2.3
DK-68	2.0	2.7	2.7	2.5
E-57+	2.3	2.7	2.7	2.6
E-57b+	2.3	2.7	2.3	2.4
E-59+	2.0	2.3	2.0	2.1
F-61+	2.0	3.0	2.0	2.3
F-64+	2.0	4.0	2.7	2.9
F-67	2.0	2.7	2.3	2.3
F-68	2.0	2.3	2.3	2.2
EX-19	2.0	2.0	2.0	2.0
Sultan	2.0	3.3	2.0	2.4
BR-45+	2.0	3.0	2.0	2.3
F-68+	2.0	2.7	2.7	2.5
BR64	2.0	2.3	2.3	2.2
Funk Seeds International				
G-251	2.0	2.3	2.0	2.1
G-261	2.0	3.0	2.0	2.3
G-393	2.0	3.0	2.0	2.3
G-404	2.0	3.0	2.0	2.3
G-499GBR	2.0	3.3	2.0	2.4
G-550	2.0	2.7	2.0	2.2

Table 2 (continued)

Sorghum genotypes from	Leaf feeding ratings			
	1981	1982	1983	Mean
G-623GBR	2.0	3.0	2.0	2.3
G-611	2.0	3.3	2.0	2.4
G-722DR	2.0	2.0	2.0	2.0
G-766W	2.0	3.0	2.0	2.3
Growers Seed Association				
SG10	2.0	2.7	2.0	2.2
GSA1290	2.0	3.3	2.3	2.5
SG39	2.0	2.7	2.0	2.2
SG17	2.0	2.3	2.0	2.1
GSA1310A	2.0	2.7	2.0	2.2
SG40GBR	2.0	3.3	2.0	2.4
E110	2.0	2.3	2.3	2.2
Cargill Seed Division				
PAG4433	2.0	3.0	2.3	2.4
PAG4474	2.0	2.3	2.0	2.1
PAG5514	2.0	2.3	2.0	2.1
PAG6658	2.0	3.0	2.3	2.4
PAG6662	2.0	3.0	2.0	2.3
Cargill 30	2.0	3.3	2.3	2.5
Cargill 50	2.0	3.0	3.0	2.7
Cargill 60	2.0	2.7	2.0	2.2
Cargill 70	2.0	2.7	2.3	2.3
Fontannelle Hybrids				
6651	2.0	2.7	2.0	2.2
5583	2.0	3.0	2.3	2.4
5547	2.0	3.0	2.0	2.3
5537	2.0	2.3	2.0	2.1
4455	2.0	2.7	2.0	2.2
Pioneer Hi-Bred International Inc.				
B815	2.0	2.3	2.0	2.1
8155	2.0	3.3	2.0	2.4
8199	2.0	3.3	2.3	2.5
8244	2.0	2.7	2.0	2.2
8272	2.0	2.3	2.3	2.2
828	2.0	3.0	2.0	2.3
2416	2.0	2.0	2.3	2.1

Table 2 (continued)

Sorghum genotypes from	Leaf feeding ratings 1981	1982	1983	Mean
8324	2.0	3.0	2.3	2.4
8308B	2.0	2.7	2.3	2.3
8328	2.0	2.0	2.0	2.0
8437	2.0	3.3	2.3	2.5
8442	2.0	3.0	2.3	2.4
845	2.0	3.0	2.0	2.3
8451	2.0	2.7	2.3	2.3
846	2.0	2.7	2.0	2.3
8475	2.0	2.3	2.0	2.1
848	2.0	2.0	2.0	2.0
8501	2.0	2.7	2.3	2.3
8585	2.0	2.0	2.0	2.0
8592	2.0	2.3	2.3	2.2
8633	2.0	2.0	2.3	2.1
866	2.0	2.3	2.3	2.2
8674	2.0	3.7	2.3	2.7
8681	2.0	2.3	2.3	2.2
8680	2.0	2.7	2.0	2.2
8877	2.0	2.0	2.0	2.0
8790	2.0	2.0	2.0	2.0
883	2.0	2.3	2.3	2.2
8901	2.0	2.0	2.0	2.0
W823	2.0	2.0	2.0	2.0
894	2.0	2.0	2.0	2.0
8202	2.0	2.3	2.0	2.1
8311	2.0	2.3	2.0	2.1
8626	2.0	2.0	2.0	2.0
8712	2.0	2.7	2.0	2.2
8855	2.0	2.0	2.0	2.0
44051	2.0	2.3	2.0	2.1
X5004	2.0	2.3	2.0	2.1
X3015	2.0	2.0	2.0	2.0
8914	2.0	2.0	2.0	2.0
X7910	2.0	2.0	2.3	2.1
X6513	2.0	2.3	2.3	2.2
X5139	2.0	2.0	2.0	2.0
878	2.0	2.3	2.3	2.2
X7939	2.0	3.0	2.0	2.3
X7969	2.0	2.7	2.0	2.2
X7926	2.0	2.0	2.0	2.0
Iowa State University				
RS-671	2.0	2.3	2.3	2.3

Table 2 (continued)

Sorghum genotypes from	Leaf feeding ratings			
	1981	1982	1983	Mean
RS-610	2.0	2.3	2.0	2.1
Wilson Hybrid	2.0	2.3	2.0	2.1
Maize genotypes				
B75	1.7	1.0	1.3	1.3
B85	1.3	1.0	1.3	1.2
B73[f]	7.3	7.7	9.0	8.3
WF9[f]	6.7	8.0	9.0	7.9
WF9x M14[f]	7.7	7.7	9.0	8.1
LSD 0.05	0.2	1.3	0.6	

[f] The susceptible genotypes of maize were not included in the analysis of variance.

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EXPERIMENT II. EUROPEAN CORN BORER: RATE OF FIRST-GENERATION LARVAL MORTALITY IN SORGHUM HYBRIDS COMPARED WITH INBRED LINES OF MAIZE DURING THE WHORL STAGE OF PLANT DEVELOPMENT

INTRODUCTION

In maize, Zea mays L., most of the European corn borer, Ostrinia nubilalis Hübner, 1st-generation larval mortality occurs during the first few days after egg hatch (Painter and Ficht, 1924; Caesar, 1925, 1926; Springer, 1930; Huber, 1936; Patch, 1943; and Guthrie et al., 1960). Over 95% larval mortality occurs within 5 days after egg hatch on inbred lines of maize that are resistant to leaf feeding by 1st-generation ECBs (Guthrie et al., 1960). Resistance to 1st-generation borers, is, therefore, leaf feeding resistance (a high level of antibiosis against 1st- and 2nd-instar larvae).

Very little research has been conducted on resistance in sorghum, Sorghum bicolor (L.), to leaf feeding by 1st-generation ECBs (Painter and Weibel, 1951; F. F. Dicke, Pioneer Hi-Bred International Inc., unpublished data). Dharmalingam (Experiment I) found 211 sorghum hybrids to be resistant to 1st-generation borers.

The purpose of Experiment II was to determine the rate of 1st-generation larval mortality in four sorghum hybrids, compared with two inbred lines of dent maize (one resistant to leaf feeding and one susceptible to leaf feeding), and to determine 1st-generation larval feeding sites in sorghum.

MATERIALS AND METHODS

Each year, the genotypes of sorghum and maize were planted in randomized blocks consisting of five-row plots. Plots were planted May 15 in 1981, on June 2 in 1982, and on May 17 in 1983. Each row was 3.3 meters long with 100 cm between rows; stands were thinned to ca. 10 cm between plants when plants were ca. 15 cm in height.

The plants in each row were artificially infested with eight egg masses (ca. 200 eggs)/plant during the midwhorl stage of plant development. The infestations were made in two applications of four masses, each spaced 1 day apart. Egg masses, incubated to near hatching, were dropped into the whorl of each plant. Infestation and egg production techniques were reported by Guthrie et al., (1960,1971).

Larval survival on the sorghum and maize genotypes was determined by dissecting a sample of ten plants in each plot 3, 6, 9, 12, and 15 days after egg hatch. Larval feeding sites were also recorded. Plant samples in each of the dissection intervals were taken at random from all plots in a split-plot arrangement. The six genotypes were on the whole plot area, and the five dissection intervals were on the split-plot area. Plot mean values were used for analysis of variance.

RESULTS AND DISCUSSION

The analyses of variance (Table 3) showed highly significant differences between genotypes, dissection intervals, and the interaction of genotypes X dissection intervals for larval survival during each of the 3 years. The performance of four sorghum hybrids and two maize inbred lines for each dissection interval of 3, 6, 9, 12, and 15 days after egg hatch, which measures the rate of 1st-generation larval mortality is of greatest interest, and the data are recorded in Tables 4, 5, and 6 for 1981, 1982, and 1983, respectively. The data on the main effect of genotypes and the main effect of dissection intervals are of little interest and are not recorded.

In 1981 (Table 4), larval survival was nearly as high on the four sorghum hybrids as was larval survival on the susceptible inbred line of maize (B73) for the 3-, 6-, 9-, and 12-day dissection intervals. Larval survival was very low on the resistant inbred line of maize (B85).

In 1982 and 1983 (Tables 5 and 6), larval survival was much higher on the susceptible maize inbred at all dissection intervals than was larval survival on the four sorghum hybrids. Larval survival on B85 was very low for all dissection intervals.

In general, larval mortality was rapid on the four sorghum hybrids (92.2 - 97.7% mortality within 6 days after egg hatch), but larval mortality was not as rapid on the four sorghum hybrids as was larval mortality on the resistant maize inbred (99.1 - 99.7% mortality within 6 days after egg hatch).

With the exception of 1981, larval survival was high through 15 days after egg hatch on the susceptible maize inbred, but was at a low level on the four sorghum hybrids and on the resistant maize inbred. The four sorghum hybrids had several pin hole type damage on whorl leaves 15 days after egg hatch, whereas the resistant maize inbred had a small number of pin holes. Pin holes in leaves are an indication that larvae survive on plants for only a short period of time. The susceptible inbred had many elongated lesions on whorl leaves.

Feeding sites were determined for 22,827 1st-generation larvae (Table 7). The majority of larvae fed on leaf tissue in the moist area deep in the whorl of sorghum and maize plants. As the plants developed beyond the whorl stage, some larvae fed on sheath, collar, and midrib tissue. Resistance in sorghum to 1st-generation borers, therefore, is resistance to leaf feeding (a high level of antibiosis against 1st- and 2nd-instar larvae) and is similar to 1st-generation resistance in maize.

Table 3. Analysis of variance for data in Tables 4, 5, and 6. Experiment II. Ankeny, Iowa

Source of variation	Degrees of freedom			1981		1982		1983	
	1981	1982	1983	Mean square	F	Mean square	F	Mean square	F
Reps.	3	3	3	114.17	2.84	18.63	3.89	4.60	1.32
Genotypes	5	5	5	541.74	13.49**	1020.46	211.79**	2265.60	651.03**
Error a	15	15	15	40.17		4.82		3.48	
Dissection intervals	3	4	4	70.19	94.32**	543.71	105.24**	634.44	204.66**
D.I. X genotypes	15	20	20	30.88	4.62**	50.67	9.81**	28.00	9.03**
Error b	54	72	72	28.31		5.17		3.00	

** Significant at the 1 percent probability level.

Table 4. Mean number of 1st-generation European corn borer larvae/plant by genotype and dissection interval. Ankeny, Iowa. 1981[a]

Genotypes	Dissection intervals[b] 3	6	9	12	15
Sorghum					
P846	24.5	10.6	5.3	2.7	0.0
P8475	27.8	13.0	6.4	3.5	0.0
P8680	42.4	9.9	4.5	0.8	0.0
P8324	28.5	15.6	9.1	6.3	0.0
Maize					
B85	3.9	0.6	1.0	0.0	0.0
B73	35.2	20.0	12.6	5.7	0.0
LSD 0.05					
Any two means between dissection intervals for the same genotype			7.5		
Any two means between genotype for the same dissection interval			10.1		

[a] Infested during midwhorl stage of plant development.

[b] Number of days plants were dissected after egg hatch; each plant was infested with eight egg masses (ca. 200 eggs), four replications of ten plants each for each entry.

Table 5. Mean number of 1st-generation European corn borer larvae/plant by genotype and dissection interval. Ankeny, Iowa. 1982[a]

Genotypes	Dissection intervals[b]				
	3	6	9	12	15
Sorghum					
P846	13.2	4.6	4.4	2.7	3.4
P8475	13.9	4.5	4.7	2.5	3.0
P8680	10.3	6.7	5.3	4.3	3.0
P8324	17.3	5.7	5.9	4.9	4.1
Maize					
B85	3.6	1.8	2.0	1.2	1.9
B73	39.6	24.7	21.4	12.9	13.0
LSD 0.05					
Any two means between dissection intervals for the same genotype			3.2		
Any two means between genotypes for the same dissection interval			3.9		

[a] Infested during midwhorl stage of plant development.

[b] Number of days plants were dissected after egg hatch; each plant was infested with eight egg masses (ca. 200 eggs), four replications of ten plants each for each entry.

Table 6. Mean number of 1st-generation European corn borer larvae/plant by genotype and dissection interval. Ankeny, Iowa. 1983[a]

Genotypes	Dissection intervals[b]				
	3	6	9	12	15
Sorghum					
P846	11.9	10.2	4.8	3.1	0.8
P8475	14.8	9.2	4.0	2.3	0.8
P8680	16.6	10.9	3.8	1.4	0.8
P8324	11.5	8.2	4.1	3.4	1.2
Maize					
B85	3.8	0.7	0.7	0.6	0.6
B73	42.5	35.2	30.2	25.7	20.6
LSD 0.05					
Any two means between dissection interval for the same genotype			2.4		
Any two means between genotypes for the same dissection interval			3.4		

[a] Infested during midwhorl stage of plant development.

[b] Number of days plants were dissected after egg hatch; each plant was infested with eight egg masses (ca. 200 eggs), four replications of ten plants for each entry.

Table 7. Feeding sites of 1st-generation European corn borer larvae (averaged over 3 years) on sorghum hybrids compared with maize inbred lines. Experiment II. Ankeny, Iowa

Genotypes	Dissection intervals	Larval location (%) Whorl	Sheath	Collar	Midrib	Total larvae for 3 years
Sorghum hybrids						
P846	3	92.3	6.3	1.4	0	1381
	6	93.3	5.0	1.7	0	980
	9	92.0	6.4	1.6	0	451
	12	75.8	11.8	9.3	3.1	289
	15	51.5	27.3	6.8	14.4	132
P8475	3	91.0	8.2	0.8	0	1592
	6	90.8	7.1	2.1	0	819
	9	85.5	9.4	4.5	0.6	449
	12	55.9	25.1	16.0	3.0	263
	15	44.7	36.8	15.1	3.3	152
P8680	3	93.2	6.1	0.7	0	1747
	6	77.5	11.8	10.7	0	670
	9	75.8	10.1	4.0	1.0	496
	12	61.6	25.2	10.0	3.2	250
	15	34.6	47.7	12.4	5.3	153
P8324	3	96.5	2.9	0.6	0	1610
	6	91.1	5.9	3.0	0	742
	9	85.9	10.1	4.0	0	546
	12	75.3	12.2	11.3	1.1	441
	15	42.4	40.0	11.0	6.7	210
Maize inbreds						
B85	3	93.4	6.6	1.0	0	310
	6	91.1	8.2	0.7	0	280
	9	70.7	29.3	0	0	82
	12	26.3	54.4	10.5	8.8	57
	15	29.3	55.2	12.1	3.4	58
B73	3	94.3	3.8	1.9	0	2505
	6	96.7	2.3	1.0	0	2082
	9	88.2	10.1	1.3	0.4	1648
	12	78.7	16.0	5.1	0.2	1223
	15	70.6	28.5	0.4	0.5	1209

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EXPERIMENT III. SURVIVAL AND DEVELOPMENT OF EUROPEAN CORN BORER LARVAE REARED ON MERIDIC DIETS CONTAINING DRIED-GROUND SORGHUM AND MAIZE LEAVES

INTRODUCTION

Resistance in maize, Zea mays L., to leaf feeding by 1st-generation European corn borers (ECB), Ostrinia nubilalis Hübner, has been easy to find (Guthrie and Dicke, 1972; Russell and Guthrie, 1979); 34 of the 99 most widely used inbred lines of maize (developed by the public sector) in the U.S.A. are resistant or intermediate in resistance to 1st-generation ECBs (Guthrie et al., 1983).

Genotypes of maize range from highly resistant to highly susceptible to leaf feeding by 1st-generation ECBs, whereas sorghum, Sorghum bicolor (L.), varieties and hybrids evaluated thus far are resistant to leaf feeding damage during the whorl stage of plant development (Painter and Weibel, 1951; Dicke, Pioneer Hi-Bred International Inc., unpublished data; also see Experiments I and II in this dissertation).

The purpose of Experiment III was to determine survival and development of ECB larvae reared on meridic diets containing leaves (substituted for wheat germ) of four sorghum hybrids compared with meridic diets containing leaves of two highly resistant and two susceptible genotypes of dent maize. Guthrie et al. (1980) showed that meridic diets containing leaves of susceptible genotypes of maize and meridic diets containing wheat germ were equally effective for rearing ECB larvae. The question we wanted answered was: Will ECB larvae survive on diets containing sorghum leaves or on diets containing leaves of highly resistant genotypes of maize?

MATERIALS AND METHODS

Four sorghum hybrids and four genotypes of maize were planted in single-row plots (15 meters long, 100 cm between rows) on May 15, 1981. Stands were thinned to ca. 10 cm between plants when plants were ca. 15 cm in height.

Whorl leaves from 120 plants in each of the sorghum and maize genotypes were cut during the midwhorl stage of plant development (ca. 70 cm in extended leaf height). The sorghum hybrids (P846, P8475, P8680, and P8324 from Pioneer Hi-Bred International Inc.) are resistant to leaf feeding by 1st-generation ECBs (see Experiments I and II). The maize inbred lines B75 and B85 are highly resistant to leaf feeding by 1st-generation borers; maize inbred line B73 and maize single-cross hybrid WF9 X M14 are susceptible (Guthrie et al., 1983, see also Experiment I). The whorl leaves were dried (45°C), ground into a fine powder, and stored in plastic bags at -23°C until used.

First-instar larvae (from an ECB culture reared on a meridic diet for four generations) were reared individually in 3-dram vials on plugs of diet. Plugs were cut from diet containing the dried-ground leaves of sorghum and maize (in substitution for wheat germ), from diet containing wheat germ (used as one check), and from diet containing all ingredients except wheat germ or leaves (used as a 2nd check). Diets (Table 8) were prepared as described by Guthrie et al. (1971). Agar in water was melted at 90°C. The dried-ground sorghum and maize leaves were added after the agar-water solution was cooled to 70°C; this temperature was maintained for 15 minutes and then the agar-water-leaf solution was cooled to 58°C before all other ingredients were added.

Table 8. Ingredients for European corn borer diet

Ingredients	Quantity (1 batch)
Water	13,000 g
Agar	280 g
Wheat germ, sorghum leaves, or maize leaves	540 g
Dextrose	400 g
Casein	440 g
Cholesterol	32 g
Salt mixture #2	144 g
Vitamin supplement	92 g
Ascorbic acid	120 g
Aureomycin	27 g
Fumidil B	7 g
Methyl p hydroxybenzoate	21 g
Propionic acid	86 ml
Formaldehyde	7 ml
Sorbic acid	8 g

Larvae were placed on plugs of diet in vials with a small artist's brush, and the vials were placed in trays containing 10 rows of 17 vials/row. Each row contained one of the ten diets. A randomized block design was used with the ten diets randomized within each tray, and each tray was a single replication. The experiment was replicated 20 times for a total of 340 larvae on each diet (3400 larvae for the experiment).

The criteria used for evaluating the effect of diet on larval survival and development were: (1) percentage survival to pupation, (2) percentage survival to adult emergence, (3) number of days to pupation, (4) number of days to adult emergence, and (5) weights of female and male pupae. Diet means were used for analysis of variance.

RESULTS AND DISCUSSION

The significant F values in Table 9 are due primarily to diet number 10 which contained all ingredients except wheat germ or maize leaves. Percentage larval survival to pupation and to adult emergence was low. The larvae that did survive took a long time to pupate and to emerge as adults, and the female and male pupae were small (Table 10). This information shows the importance of wheat germ or dried-ground leaves of maize in a meridic diet for rearing ECB larvae.

The four sorghum hybrids (P846, P8475, P8680, P8324) and two inbred lines of dent maize (B75, B85) are highly resistant to leaf feeding by 1st-generation ECBs; maize inbred B73 and single-cross WF9 X M14 are susceptible to 1st-generation borers (see Experiment I).

Beck and Lilly (1949) showed that larval mortality in sorghum was correlated with cyanide content of the leaves. We did not determine the cyanide content of the sorghum hybrids in Table 10.

DIMBOA (2, 4-dihydroxy-7-methoxy-(2H)-1,4-benzoxazin-(4H)-one), which occurs as a glucoside in intact maize tissue, is a biochemical factor in the resistance of maize to leaf feeding by 1st-generation ECBs (Klun et al., 1967).

Drying the sorghum and maize leaves and cooking the meridic diet under high temperature conditions probably destroyed most, if not all, of the cyanide content in sorghum leaves and DIMBOA content in maize leaves because dried-ground leaves (in a meridic diet) of the resistant genotypes of sorghum and maize had no deleterious effect on survival and development of ECB larvae compared with diet containing susceptible genotypes of maize and compared with a standard wheat germ diet (Table 10).

Larval survival to pupation and to adult emergence and pupal weights were high in all diets containing sorghum or maize leaves and in the diet containing wheat germ. Larvae reared on diet containing wheat germ, however, pupated (1.5-2.8 days) and emerged as adults (1.9-3.3 days) earlier than did larvae reared on diets containing sorghum or maize leaves.

Table 9. Analysis of variance for data in Table 10. Experiment III. Ankeny, Iowa

Source of variation	Degrees of freedom	Percentage survival to: Pupation Mean square	Pupation F	Adult Mean square	Adult F	Number of days to: Pupation Mean square	Pupation F	Adult Mean square	Adult F
Reps	19	55.84		99.97		2.84		3.13	
Diets	9	831.01	16.39**	2529.85	37.54**	154.54	420.74**	178.57	362.72**
Error	171	50.70		67.39		0.37		0.49	

Source of variation	Degrees of freedom	Weight (mg): Female Mean square	Female F	Male Mean square	Male F
Reps	19	163.16		95.42	
Diets	9	1720.08	86.36**	803.63	61.02**
Error	171	19.92		13.17	

** Significant at the 1 percent probability level.

Table 10. Survival and development of European corn borer larvae reared on meridic diets. Experiment III. Ankeny, Iowa. 1982

		Percentage survival to		Number of days to		Pupal weight (mg)	
Diet	Genotype	Pupation	Adult	Pupation	Adult	Female	Male
	Sorghum						
1	P846[a]	92.6	90.1	17.5	25.3	94.9	73.2
2	P8475[a]	97.6	94.4	17.7	25.5	94.3	72.6
3	P8680[a]	93.5	91.5	18.1	25.8	95.2	73.7
4	P8324[a]	95.9	93.2	17.7	25.5	102.5	76.3
	Maize						
5	B75[b]	93.8	92.3	18.7	26.6	98.2	73.9
6	B85[b]	94.4	90.6	18.2	26.0	99.4	75.3
7	B73[b]	95.9	93.8	17.4	25.2	104.8	77.7
8	WF9XM14[c]	98.2	96.5	17.9	25.7	100.7	75.3
	Other						
9	W. G.[d]	94.7	91.8	15.9	23.3	94.6	72.6
10	Check[e]	75.6	57.6	26.2	34.5	71.3	55.1
	LSD 0.05	4.45	5.13	0.38	0.47	2.79	2.27

[a] Meridic diet (14,550 gm batch) contained 540 gms of dried-ground sorghum leaves (stored at 4°C for 6 months) instead of wheat germ.

[b] Meridic diet (14,550 gm batch) contained 540 gms of dried-ground maize leaves (stored at 4°C for 6 months) instead of wheat germ.

[c] Meridic diet (14,550 gm batch) contained 540 gms of dried-ground maize leaves (stored at -23°C for 15 years) instead of wheat germ.

[d] Meridic diet (14,550 gm batch) contained 540 gms of wheat germ instead of dried-ground leaves.

[e] Meridic diet (14,550 gm batch) did not contain wheat germ or dried-ground leaves.

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EXPERIMENT IV. EUROPEAN CORN BORER: RATE OF SECOND-GENERATION LARVAL MORTALITY IN SORGHUM HYBRIDS COMPARED WITH INBRED LINES OF MAIZE DURING ANTHESIS

INTRODUCTION

During the period of egg deposition by 2nd-generation European corn borers (ECB), Ostrinia nubilalis Hübner, in the Maize Belt states, maize, Zea mays (L.), is in various stages of anthesis. The initial establishment by 1st-instar larvae is primarily on sheath and collar tissue (Guthrie et al., 1970). Resistance to 2nd-generation ECBs is, therefore, primarily sheath-collar feeding resistance.

Resistance to sheath-collar feeding in maize by 2nd-generation ECBs is polygenic; at least 7 genes are involved (short arms of chromosomes 1, 3, and 5 and long arms of chromosomes 1, 2, 4, and 8: Onukogu et al., 1978), and the type of gene action is primarily additive, although resistance is partially dominant (Jennings et al., 1974a, 1974b; Sadehdel-Moghaddam et al., 1983).

Infestations in sorghum, Sorghum bicolor (L.) by the ECB have been reported by several investigators in several countries (Caffrey and Worthley, 1927; Hodgson, 1928; Huber et al., 1928; Thompson and Parker, 1928; Babcock and Vance, 1929; Dicke, 1932; Clark, 1934; and Hsu, 1936); these infestations probably occurred during anthesis. ECB infestations in Manchuria and northern Chosen usually ranged from 15 to 30 percent; during one season, 981,175 larvae were collected from sorghum plants (Clark, 1934).

In Massachusetts, Hodgson (1928) found that the kafir types of sorghum contained the least larvae per infested plant, feterita varieties contained the most, and the hegari and milo varieties were usually intermediate.

Painter and Weibel (1951) found that stalk breakage was most common just above the flag leaf and in or just below the head. The cavities from larvae feeding in the stalks of sorghum occupied more of the diameter of the stalk and were shorter, compared with cavities in maize because of the more slender stalk.

Dicke et al. (1963) evaluated several varieties of sorghum for resistance to 2nd-generation ECBs. Artificial infestations (60-80 eggs/ plant) were made during anthesis. The best method for evaluating relative degrees of resistance was to split the stalk from the seed head to the top node and count the cavities in the peduncle area. Number of larvae was a poor index because many larvae had disappeared by time of examination. Peduncle cavity counts were highly correlated with both number of sheath lesions and total stalk cavity counts (sheath lesions sometimes were difficult to identify after the leaves were dried and broken). In general, the kafir and feterita varieties were low in number of sheath lesions, cavities, and larvae. The kaoliang types were low to moderate. The durra, shrock, and hegari varieties were moderately heavy to heavy, and the milo types were among the more heavily infested varieties.

The genetics of resistance to 2nd-generation ECBs in sorghum is not known, but several genes are probably involved. Progress has been made in breeding for resistance in sorghum with recurrent selection in S_1 lines from two random-mating populations (Atkins et al., 1983).

The purpose of Experiment IV was to determine the rate of 2nd-generation larval mortality in four sorghum hybrids compared with three inbred lines of dent maize (two resistant to sheath-collar feeding and one susceptible to sheath-collar feeding) and to determine 2nd-generation larval feeding sites in sorghum.

MATERIALS AND METHODS

Each year, the genotypes of sorghum and maize were planted (in 1981 on May 15, in 1982 on June 2, and 1983 on May 17) in randomized blocks consisting of 6-row plots. Each row was 3.3 meters long with 100 cm between rows; stands were thinned to ca. 10 cm between plants when plants were ca. 15 cm in height.

Ten plants in each row were artificially infested with eight egg masses (ca. 200 eggs)/plant during anthesis. The infestations were made in two applications of four masses, each spaced 1 day apart. Egg masses, incubated to near hatching, were pinned through the midrib under the middle four leaves at anthesis.

Infestation and egg production techniques were reported by Guthrie et al. (1971). Larval survival on the sorghum and maize genotypes was determined by dissecting ten plants in each plot 3, 6, 9, 12, 15, and 35 days after egg hatch. Larval feeding sites were also recorded. The plants in each of the dissection intervals were taken at random from all plots in a split-plot arrangement. The seven genotypes were on the whole plot area, and the six dissection intervals were on the split-plot area. Plot mean values were used for analysis of variance.

RESULTS AND DISCUSSION

The analyses of variance (Table 11) showed highly significant differences between genotypes and dissection intervals in 1981, 1982, and 1983. In 1981 and 1983, the interaction of dissection intervals X genotypes was also highly significant.

The performance of four sorghum hybrids and three maize inbred lines for each dissection interval of 3, 6, 9, 12, 15, and 35 days after egg hatch, which measures the rate of 2nd-generation larval mortality, is of greatest interest, and the data are recorded in Tables 12, 13, and 14 for 1981, 1982, and 1983, respectively. The data on the main effect of genotypes and the main effect of dissection intervals are of little interest and are not recorded.

ECB larval survival was much higher on the susceptible inbred line of maize (B73) at most dissection intervals than was larval survival on the four sorghum hybrids and the two resistant (B86 and B52) maize inbreds (Tables 12, 13, and 14).

The four sorghum hybrids were as resistant to 2nd-generation ECB larvae as were the two resistant inbred lines of maize. Larval mortality was rapid on the four sorghum hybrids (93.9 - 98.9% mortality within 6 days after egg hatch), and on the two resistant maize inbreds (92.6 - 97.8% mortality within 6 days after egg hatch). This high rate of larval mortality is a high degree of antibiosis against the 1st- and 2nd-instar larvae of a 2nd-generation ECB infestation.

Feeding sites were determined for 33,690 2nd-generation larvae (Table 15). The majority of larvae fed on sheath-collar tissue through 35 days after egg hatch of sorghum plants and through 15 days after egg hatch on maize plants. Some larvae fed in the peduncle of sorghum plants 35 days after egg hatch and in the stalk of maize plants 35 days after egg hatch. These data confirm previous data on larval feeding sites in maize (Guthrie et al., 1970), i.e., the initial establishment by 1st-instar larvae is primarily on sheath-collar tissue. Resistance in sorghum to 2nd-generation ECBs as in maize, therefore, is resistance to sheath-collar feeding.

Table 11. Analysis of variance for data in Tables 12, 13, and 14. Experiment IV. Ankeny, Iowa

Source of variation	Degrees of freedom			1981		1982		1983	
	1981	1982	1983	Mean square	F	Mean square	F	Mean square	F
Reps.	3	3	3	14.23	0.58	98.76	3.97	5.33	0.71
Genotypes	5	6	6	1229.34	49.70**	1310.50	52.71**	1512.27	202.18**
Error a	15	18	18	24.74		24.86		7.48	
Dissection intervals	5	5	5	626.75	53.44**	305.82	11.65**	463.26	95.52**
D.I. X genotypes	25	30	30	69.16	5.90**	28.27	1.08 ns	19.10	3.94**
Error b	90	105	105	11.73		26.24		4.85	

** Significant at the 1 percent probability level.

ns Nonsignificant.

Table 12. Mean number of 2nd-generation European corn borer larvae/plant by genotype and dissection interval. Ankeny, Iowa. 1981[a]

Genotypes	Dissection intervals[b]					
	3	6	9	12	15	35
P846	14.0	3.0	2.6	1.3	0.7	1.4
P8475	10.6	11.2	2.1	1.4	1.0	1.9
P8680	3.4	2.5	1.3	1.1	1.4	1.4
P8324	19.4	2.8	4.3	0.6	1.5	1.5
Maize						
B86	18.1	14.8	5.5	8.0	8.8	5.7
B73	39.5	18.4	27.3	18.5	15.6	8.5
LSD 0.05						
Any two means between dissection intervals for the same genotype			4.8			
Any two means between genotypes for the same dissection interval			2.7			

[a]Infested during anthesis.

[b]Number of days plants were dissected after egg hatch; each plant was infested with eight egg masses (ca. 200 eggs), four replications of ten plants each for each entry.

Table 13. Mean number of 2nd-generation European corn borer larvae/plant by genotype and dissection interval. Ankeny, Iowa. 1982[a]

Genotypes	Dissection intervals[b]					
	3	6	9	12	15	35
Sorghum						
P846	6.9	9.3	3.7	3.8	2.8	1.5
P8475	7.8	7.3	4.9	5.1	3.8	3.2
P8680	3.0	2.2	1.9	2.7	2.0	0.6
P8324	10.9	12.2	5.6	2.7	2.6	1.8
Maize						
B86	20.0	9.0	8.5	6.9	9.5	8.0
B52	14.7	13.3	10.7	8.1	7.4	6.4
B73	36.8	26.9	24.8	22.7	19.3	15.7
LSD 0.05						
Any two means between dissection intervals for the same genotype			7.2			
Any two means between genotypes for the same dissection interval			9.1			

[a] Infested during anthesis.

[b] Number of days plants were dissected after egg hatch; each plant was infested with eight egg masses (ca. 200 eggs), four replications of ten plants each for each entry.

Table 14. Mean number of 2nd-generation European corn borer larvae/plant by genotype and dissection interval. Ankeny, Iowa. 1983[a]

Genotypes	Dissection intervals[b]					
	3	6	9	12	15	35
Sorghum						
P846	9.8	10.2	5.6	3.2	1.0	0.4
P8475	15.6	10.8	8.5	3.5	1.6	0.6
P8680	7.4	5.7	4.3	2.2	2.0	0.2
P8324	11.1	6.0	3.0	2.1	1.2	0.7
Maize						
B86	10.1	9.9	9.2	5.8	5.5	2.8
B52	9.7	4.2	3.2	2.5	2.2	2.4
B73	39.3	26.2	26.3	23.3	20.4	19.2
LSD 0.05						
Any two means between dissection intervals for the same genotype			3.1			
Any two means between genotypes for the same dissection interval			4.5			

[a] Infested during anthesis.

[b] Number of days plants were dissected after egg hatch; each plant was infested with eight egg masses (ca. 200 eggs), four replications of ten plants each for each entry.

Table 15. Feeding sites of 2nd-generation European corn borer larvae (averaged over 3 years) on sorghum hybrids compared with maize inbred lines. Experiment IV. Ankeny, Iowa

Genotypes	Dissection intervals	Larval location (%)						Total larvae for 3 years
		Collar	Sheath	Head	Stalk	Peduncle	Midrib	
Sorghum hybrids								
P846	3	83.6	14.0	2.4	0	0	0	1247
	6	69.1	23.7	7.2	0	0	0	854
	9	46.1	43.8	10.0	0	0	0.1	482
	12	46.4	47.7	4.3	0	0	2.6	323
	15	23.4	64.0	8.6	0	2.9	1.1	175
	35	8.6	73.4	10.2	1.5	6.3	0	128
P8475	3	81.9	15.5	2.6	0	0	0	1346
	6	80.0	15.5	4.6	0	0	0	1174
	9	51.3	38.0	10.1	0	0.6	0	624
	12	41.8	54.1	3.5	0	0.6	0	373
	15	15.0	71.8	4.5	0	3.7	5.0	266
	35	23.0	40.0	15.8	0	14.6	6.6	165
P8680	3	69.0	27.7	3.3	0	0	0	541
	6	58.5	34.1	7.4	0	0	0	414
	9	52.8	40.8	6.4	0	0	0	299
	12	41.0	46.4	11.3	0	1.3	0	239
	15	31.8	55.1	9.8	0	0	3.3	214
	35	15.9	46.6	3.4	15.9	10.2	8.0	88
P8324	3	90.0	8.4	1.6	0	0	0	1658
	6	70.2	19.6	9.2	0	1.0	0	838
	9	60.3	30.4	8.0	0	1.3	0	514

Table 15 (continued)

Genotypes	Dissection intervals	Larval location (%)						Total larvae for 3 years
		Collar	Sheath	Head	Stalk	Peduncle	Midrib	
P8324	12	25.1	63.3	8.4	0	0	3.2	215
	15	37.4	41.8	15.5	0	1.0	4.3	206
	35	21.3	47.5	14.2	0	12.1	4.9	141
Maize inbreds		Collar	Sheath	Tassel	Stalk	Husk	Silk-ear	
B86	3	78.0	11.5	4.8	0	4.9	0.8	792
	6	79.9	11.2	0	0	6.2	2.7	1233
	9	57.2	20.3	1.5	0.3	12.4	8.3	718
	12	34.4	38.2	0.5	7.5	9.6	9.8	671
	15	17.8	44.4	7.6	10.3	7.1	12.8	755
	35	5.7	34.1	0	19.5	3.2	37.5	523
B52	3	68.5	16.9	4.1	0	8.8	1.7	930
	6	50.3	25.6	3.2	1.5	15.9	3.5	680
	9	49.3	27.8	1.0	5.8	10.5	5.6	515
	12	12.3	34.4	0	9.3	11.8	31.2	398
	15	22.8	30.2	0	11.1	9.2	26.7	360
	35	3.2	27.1	0	23.2	8.9	37.6	314
B73	3	81.2	13.4	0.3	0	4.3	0.8	3882
	6	79.9	10.8	0.1	0	7.6	1.7	2072
	9	69.3	15.2	0.8	3.0	8.3	3.4	2678
	12	44.5	28.5	2.2	10.7	8.7	5.4	2093
	15	19.7	44.9	0	7.7	9.9	17.8	1040
	35	1.7	19.7	0	73.0	0.5	5.1	1512

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SUMMARY AND DISCUSSION

In 1981, 1982, and 1983, 211 sorghum genotypes were evaluated for resistance to leaf feeding by 1st-generation ECB larvae under very heavy infestation conditions (ca. 750 eggs/plant/season). There were significant differences between some of the sorghum genotypes and between some of the sorghum genotypes compared with two resistant maize inbred lines. All sorghum genotypes, however, were resistant to leaf feeding by 1st-generation ECBs. The leaves on the sorghum genotypes had pin holes, similar to those on resistant genotypes of maize, but had no elongated lesions (indicating that some larvae lived for a short time on leaf tissue). Leaf damage on sorghum, in our opinion, was insufficient to cause economic yield losses.

The rate of 1st-generation larval survival on four sorghum hybrids and two inbred lines of maize was determined by dissecting plants 3, 6, 9, 12, and 15 days after egg hatch (infestations with ca. 200 eggs/plant were made during the midwhorl stage of plant development). Larval survival was much higher on a susceptible maize inbred line at most dissection intervals than was larval survival on four sorghum hybrids and on a resistant inbred line of maize. In general, larval mortality was rapid on four sorghum hybrids (92.2 - 97.7% mortality within 6 days after egg hatch), but larval mortality was not as rapid on the four sorghum hybrids as was larval mortality on a resistant maize inbred (99.1 - 99.7% mortality within 6 days after egg hatch). Feeding sites were determined for 22,827 1st-generation larvae. The majority of larvae fed on leaf tissue in the moist area deep in the whorl of sorghum and maize plants. Resistance in sorghum to 1st-generation ECBs, therefore, is resistance to leaf feeding (a high level of antibiosis against 1st- and 2nd-instar larvae) and is similar to 1st-generation resistance in maize.

Survival and development of ECB larvae reared on meridic diets containing whorl leaves (substituted for wheat germ) of four sorghum hybrids compared with meridic diets containing leaves of two highly resistant and two susceptible genotypes of maize were determined. Dried-ground leaves (in a meridic diet) of the resistant genotypes of sorghum and maize had no deleterious effect on survival and development of ECB larvae compared with a diet containing leaves of susceptible maize and compared with a standard wheat germ diet. Larval mortality in sorghum has been correlated with cyanide content of the leaves, and DIMBOA (2,4-dihydroxy-7-methoxy-2(2H)-1,4-benzoxazin-(4H)-one) is a biochemical factor in the resistance of maize to leaf feeding by 1st-generation ECBs. Drying the sorghum and maize leaves and cooking the meridic diet under high temperature conditions probably destroyed most, if not all, of the cyanide content in sorghum leaves and DIMBOA content in maize leaves.

The rate of 2nd-generation larval survival was determined by dissecting plants 3, 6, 9, 12, 15, and 35 days after egg hatch (infestations with ca. 200 eggs/plant were made during anthesis). Larval survival was much higher on the susceptible inbred line of maize at most dissection intervals than was larval survival on four sorghum hybrids and two resistant maize inbreds. Larval mortality was rapid on the four sorghum hybrids (93.9 - 98.9% mortality within 6 days after egg hatch) and on the two resistant maize inbreds (92.6 - 97.8% mortality within 6 days after egg hatch). This high rate of larval mortality is a high degree of antibiosis against 1st- and 2nd-instar larvae of a 2ndgeneration ECB infestation. Feeding sites were determined for 33,690 2nd-generation larvae. The majority of larvae fed on sheath-collar tissue through 35 days after egg hatch of sorghum plants and through 15 days after egg hatch on maize plants. Resistance in sorghum to 2nd-generation ECBs as in maize, therefore, is resistance to sheath-collar feeding.

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ACKNOWLEDGMENTS

I am grateful to Dr. W. D. Guthrie, major professor, for his guidance in conducting the research and freely giving his time for constant counsel throughout our stay at Iowa State University. I am also grateful to Drs. R. E. Atkins, J. L. Jarvis, J. A. Mutchmor, and D. C. Norton for serving as committee members.

I thank Mary Lodholz and Elva Olson for rearing the European corn borer on a meridic diet and for preparing egg masses for artificial infestations, and I thank Jim Robbins for assisting with artificial infestations. I am grateful to C. T. Tseng for assisting with dissection of sorghum and maize plants, and to Marian McIntosh for typing the dissertation.

I sincerely acknowledge the kindness and consideration shown by Mrs. Guthrie, Mrs. Jarvis, and Mrs. Robbins during our stay in this country. I am personally grateful to Dr. Guthrie and Mr. Robbins, and to all personnel of the Corn Insects Research Unit, and Department of Entomology for their kindness.

I am grateful to my wife, Jokeswari, and daughter Dharshini for their patience.

I thank FAO for providing a 2-year fellowship and the Department of Agriculture, Sri Lanka for granting me the study leave. I also thank the Department of Entomology, Iowa State University for providing financial assistance during the last year of my studies.