D E D I C A T I O N

This manuscript is dedicated

To the honorable Sudanese people;...the most magnanimous..,

My parents..............,

and to Hajja - Fatima....

RECOVERY RESISTANCE IN GRAIN SORGHUM TO SPOTTED STEM BORER *Chilo partellus* SWINHOE (LEPIDOPTERA: PYRALIDAE)

By

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ABSTRACT

The production of effective tillers in some sorghum genotypes after the attack by _Chilo partellus_ (Swinhoe) is known as recovery resistance. The present studies were conducted at ICRISAT Center with the following objectives: (1) study time and pattern of tiller appearance in relation to _C. partellus_ infestation and damage, (2) relate tiller growth and development to resistance to stem borer, (3) study fate of tillers under _C. partellus_ infestation, and (4) investigate seasonal effects on tillering and recovery resistance to _Chilo_ infestation.

The initial phase in these studies was field screening of 228 Sudanese sorghum germplasm accessions for recovery resistance to stem borer, followed by glassehouse screening for 48 lines selected from the field screening. Eight lines with the highest level of tiller survival were retained and further evaluated under both rainy and post-rainy season conditions. The evaluations were conducted under three infestation levels (i.e. no infestation, main stem infestation, and main stem with tiller infestation). Tiller infestation were done according to three age groups, i.e. 14, 21 , and 28-day old. Plants were infested artificially with laboratory-reared insects. The results were as follows:

(1) Significant differences were recorded between the treatments and genotypes in total number of tillers produced per plant. Wide and considerable differences were recorded in pattern of tiller appearance under _C. partellus_ infestation between the two seasons.

(2) Differences between the lines in tillers leaf damage were significant. The differences in tiller deadheart formation were also significant. In post-rainy season and in younger tillers the vigor (height of tiller) was more important for their survival. With aging, tillers of early maturing lines showed relatively less deadheart formation than late maturing ones. The two lines IS 19474 and IS 22806 showed relatively faster tiller growth when recorded at 20 and 24 days after tiller appearance. The same lines recorded low deadheart formation in tillers 21 and 28-day old in rainy season. Considerable differences between healthy and deadheart plants in tiller growth were detected. In rainy season, severe damage was recorded in tillers infested at 14-day old with the lowest being in IS 3492 and IS 9751. Those two lines showed extensive tiller production and faster tiller growth in healthy plants. Weak apical dominance seems to be an advantage related to tiller survival. Rapid tiller growth in deadheart or non-deadheart plants provided better chances of escape from stem borer damage.

(3) Tillers were attacked by the insect even when infesting only the main stem; damage occurred in the form of deadheart and breakage, particularly in juvenile ones. Some tillers died naturally. The results also showed significant differences between treatments and genotypes in fate of tillers under stem borer

infestation. Under rainy season conditions the proportion of tillers died naturally was greater than in post-rainy season.

(4) The results showed significant seasonal differences in the total number of tillers produced per plant and their percent contribution in total grain yield. Under post-rainy season conditions the genotypes manifested greater potentialities for tiller production and greater contribution of tillers in total grain yield. In most cases deadheart formation was not correlated with percent reduction in grain yield.

(5) The results of insect induced tillering showed significant differences (P= 0.05) between insect infested and mechanically damaged plants in number of tillers produced per plant. In some cases plants respond to insect infestation by manifesting better growth in tillers in non-deadheart plants.

بسم الله الرحمن الرحيـــــم

ملخص الاطروحـة

اجريت هذه الدراســـة والتي تتعلـق بموضـوع مقاومـة التخليـــف (Recovery resistance) في الذرة الرفيعـة لحشرة ثاقبة الســاق (Chilo partellus Swinhoe) رتبة:حرشفيات الاجنحة (Lepidoptera)، عائلة : البايراليدى (Pyralidae) بالمركز الدولي لبحوث المحاصـيل للمناطق المدارية شبه الجافة (ICRISAT) بالـهند. كانت اهداف الدراسـة هـى :

(١) دراسة طريقة ظهور الخلف (Tillers)* مع الزمن تحـت تأثير الاصابة بحشرة ثاقبة الساق.

(٢) دراسة العلاقة بين بعض العوامل النباتية كمعدلات نمو الخلف (Tiller growth) وفترات نضجها ومستوى معدلات حياتهـا (Tiller survival) في وجود الحشـرة .

(٣) معرفة مصير المجموع الكلى المنتج من الخلف عند تعّـرض النباتات للاصابة بالحشرة.

(٤) دراسة التأثيرات الموسمية في عملية انتاج الخلف ومن ثم فـي مقدرات النباتات على اظهار مقاومة التخليف.

دراسة الهدفين ٢ و ٤ تقتضى الحصول على عينات لها مستويات من مقاومة التخليف. لذلك بدأت هذه الدراسة بعدد ٢٢٨ عينة ذرة سودانيـة الموطن،تم اختيارها على أساس عدم الحساسية لفترة الضوء اليومـي (Photo-period-insensitivity) وذلك حتى يمكن دراسة الهدف الاخير باختبار الفرضـية القائلة بتأثير درجة الحرارة على مقاومة التخليف. ذلك من خـلال اجراء الدراسات للعينات التي يتم اختيارها في موسم المطر او الخريـف والموسم بعد المطرى او الربيــع (Post-rainy or rabi season) حيث تكون درجات الحرارة منخفضة. كذلك روعي ان تكون العينات مختلفة في فترات نضجها مع تنوع مناطق تجميعها من السودان. نظرا لقلة مسـتوى الاصابة بحشرة ثاقبة الساق بمركز ICRISAT، تم الاعتماد على الاصـابة الصناعية (Artificial infestation) عن طريق استخدام جهاز البازوكا (Bazooka applicator) . رُبيت الحشرة على بيئة غذائية صناعية حسب الطريقة المتبعة بمعمل تربية ألحشرات بالمركز. تمت اصابة العينات عندمـا كان عمر المحصول ١٥ يوما بعد الانبات. كذلك زرعت مع العينات بعـض

* الترجمة العربية للكلمة Tillers هى أشطاء و Tillering هـى إشطاء حسبما ورد في معجم "الشهابي في مصطلحات العلوم الزراعيـة"، الطبعة الثالثة ، عام ١٩٨٨ ، لبنان . الا انه تـم استعمـال كلمة "خِلف" لشيوعها في السودان .

العينات المقاومة وغير المقاومة بهدف المقارنة ٠ ادى تدخل ذبابة الساق (Shoot fly) والتى بلغت اصابتها حوالى ٤ر٣٩٪ الى اعتبار هذه الخطوة مرحلة بحث او تصفية (Screening) ابتدائية للعينات ٠ نتج عن ذلك اختيار ثمانية واربعين (٤٨) عينة على أساس التقييم عن طريق النظر (Visual rating) لمقاومة التخليف٠

في مرحلة تصفية اخرى تمت زراعة الثمانية واربعين عينة على مجموعتين على الاصص البلاستيكية خارج البيوت الزجاجية فى شكل تجربة موزعة توزيعا عشوائيا كاملا (Complete Random Design) مع خمسة مكررات٠ اصيبت النباتات صناعيا فى عمر ١٠ ايام بعد الانبات ٠ كان عدم وجود المساحة اللازمة هو السبب فى زراعة العينات على مجموعتين ٠ الاولى تضم ٣٢ مع خمسة عينات للمقارنة منهم العينة "سيرينا" (Serena) اليوغندية المعروفة بمقاومة التخليف لحشرة ذبابة الساق والثانية مكونة من ١٦ عينة فى وجود عينتين للمقارنة٠ فى هذه المرحلة تم جمع معلومات مكثفة فيما يتعلق بمستوى اصابة الاوراق ونسبة موت القمة النامية (Deadheart) وكذلك عدد وتاريخ ظهور الخلف ٠ نتيجة لاصابة الخلف بالحشرة ايضا تم تحديد نسبة الموت بالنسبة لهم٠ ايضا نسبة لوجود بعض النباتات التى لم تستطع ان تنتج خلف او تواصل التخليف مما ادى الى موتها كلية ، حُسبت فى ذلك سبة النباتات التى تم تخليفها (Recovered plants) ٠ كذلك تم التقييم عن طريق النظر لظاهرة مقاومة التخليف ٠ من المجموعة التى تضم ٣٢ عينة اختيرت ثمانية عينات لها اعلى نسبة حياة للخلف وعليه اعتبرت هذه العينات بانها الافضل فيما يتعلق بمقاومة التخليف للحشرة ثاقبة الساق٠

فى سبيل التوصل لاهداف البحث اجريت دراسات مفصلة على العينات الثمان المختارة وكان تصميم القطع المنشقة (Split-plot Design) هو التصميم الذى استعمل فى هذه الدراسات حيث خصصت القطع الرئيسية (Main plots) للمعاملات وكان عددها ثلاثة والقطع التحت رئيسية (Sub-plots) للعينات مع اخذ ثلاثة مكررات٠ كانت الثلاثة معاملات هى: الاولى : ترك العينات بلا اصابة (المقارنة او الثابت) ، والثانية : اصابة النبات الرئيسى (Main plant) والثالثة: اصابة النبات الرئيسى والخلف٠ بخصوص اصابة الساق الرئيسى في كل من المعاملة الثانية والثالثة فلقد تمت الاصابة بعد ٢٥ و ١٥ يوما من الانبات فى موسم ما بعد المطرى والمطرى على التوالى٠ فى الموسم المطرى، وبغرض المقارنة ، زرعت مع العينات الهجين C S H 1 و ICSV 700 المقاومة لحشرة ثاقبة الساق٠

أولا : دراسة طريقة ظهور الخلف مع الزمن تحت تأثير الاصابة بالحشـــــرة
(Pattern of tiller appearance under Chilo infestation)

(١) اظهرت النتائج اختلافات معنوية بين المعاملات والعينـــــات في العدد الكلى المنتج من الخلف فى الموسمين.

(٢) كشفت الدراسة عن اختلافات واسعة بين طريقة ظهور الخلـف مع الزمن فى الموسمين :

بدأ ظهور الخلف في الموسمين قبل الاصابة واستمر في الارتفاع حتى موعـد الاصابة تقريبا ثم انخفض بعد ذلك في موسم الربيع وتوقف تماما في موســـم الخريف حيث استؤنف ظهورها بعد حدوث موت القمة مباشرة. كل ذلـــــك يعكس التأثيرات الموسمية خصوصا الاختلاف في درجات الحرارة . وكنتــــائج عرضـــية اخرى:

(٣) كانت الاختلافات في مستوى موت القمة بين العينات معنويـة. كانت العينة IS 25041 الاقل في مستوى موت القمة واكثرهم استقرارا في ذلك عاكسة بذلك مستوى مقاومة اولية (Primary resistance) نسبى لحشرة ثاقبة الساق.

(٤) كانت الاختلافات بين العينات في طول الفترة ما بين حـــدوث الاصابة وموت القمة النامية معنوية في موسم الربيع بينما لم تكـــن كذلك في موسم الخريف.

(٥) اظهرت الدراسات علاقة ارتباط موجبـــــــــــة (Positive correlation) بين مستوى موت القمة وطور الحملة (Boot stage) وهو طور وجود النورات في غمد الورقة العلم (Flag leaf) وقد استعمل كدليل على فترة النضج.

يعكس ذلك اثر فترة النضج في مستويات موت القمة النامية وبالتالي مستوى المقاومة الاولية لحشرة ثاقبة الساق.

(٦) فى موسم الربيع كانت علاقة الارتباط بين موت القمة الناميـــة وطور الحملة سالبة. لقد اظهرت العينات المبكرة النضج (IS 3492 وIS 975) اعلى مستوى موت قمة :

عزى ذلك للانتاج المفرط للخلف في هذه العينات والذى يمكن من شأنه ان يكون على حساب الساق الرئيسى مما يتسبب في اضعافه. علاوة على ذلك انخفاض معدلات النمو في موسم الربيع بسبب تأثيرات درجة الحرارة المنخفضة.

(٧) عندما قيست الزاوية المحصورة بين الخلف المبكرة والســـــاق الرئيسى للعينات كانت الاختلافات بينها معنوية في هذا الصـــــدد.

ولقد وجدت علاقة ارتباط موجبة بين هذه الزاوية ومستوى موت القمة النامية فى الساق الرئيسى

ربما يدل ذلك على ان العينات التى لها زاوية صغيرة تكون خلفها اكثر عرضة للاصابة بيرقات الحشرة المهاجرة من اعلى النبات الى اسفل لتغوص داخل الساق. ربما تُعرِّض تلك اليرقات الى بعض العوامل غير المواتية من جراء تأخيرها عن الغوص داخل الساق اثناء انشغالها بتلك الخلف، الشىء الذى من شأنه ان يقود الى انخفاض نسبة موت القمة النامية.. تشير الدلائل الى ان هذه الزاوية يمكن ان تعكس مستوى السيادة القمية (Apical dominance) فى العينات .

ثانيا: دراسة العلاقة بين بعض العوامل النباتية فى الخلف ومستوى اصابتها بثاقبة الساق

(Factors associated with tiller survival to stemborer)

لدراسة العوامل التى يمكن ان تكون ذات صلة بمعدلات حياة الخلف وبالتالى مقاومتها لحشرة ثاقبة الساق،تمت اصابة الخلف فى المعاملة الثالثة على أساس الاعمار ١٤ ، ٢١ ، و ٢٨ يوم بعد ظهورها. فى موسم الربيع نسبة لتوفر العدد المطلوب من الخلف اصيبت خلف كل العينات فى كل الاعمار المذكورة آنفا. تم ذلك بتثبيت موعد الاصابة واختيار الخلف حسب اعمارها طبقا لذلك. كان حجم العينة (Sample size) هو ١٠ خلف فى كل عمر للعينة الواحدة. وفى موسم الخريف لم يتم التمكن من الحصول على خلف من جميع الاعمار ولكل العينات حتى تتم اصابتها نسبة لقلة العدد المنتج منها بالمقارنة مع موسم الربيع . وفى هذا الموسم تمت اصابة الخلف استنادا على تاريخ ظهورها،ومن جراء ذلك استمرت عملية الاصابة على مدى ٢٧ يوما فى حين تمت كل الاصابة فى موسم الربيع على مدى ٣ ايام متتالية. تم اجراء الاصابة فى الخلف باستعمال جهاز البازوكا ذو الانبوبة القصيرة . شملت المعلومات التى جمعت فى هذا الصدد: اطوال الخلف عند اصابتها وتقييم مستوى اصابة الاوراق وموت القمة النامية فيها. كذلك جمعت معلومات تخص موعد حدوث طور الحملة فى الخلف ومعدلات نموها. تم قياس معدلات نمو الخلف بمتابعة اطوالها فى نفس الخلفة على امتداد ٢٤ يوم من موعد ظهورها. وفى موسم الخريف سجل ذلك فى المعاملة غير المصابة ومن نباتات حدث لها موت القمة النامية.

(١) مستوى اصابة اوراق الخلف (Leaf damage in tillers)

(أ) كانت الاختلافات معنوية فى مستوى اصابة اوراق الخلف بين العينات فى العمر الواحد.

(ب) ايضا كانت الاختلافات بين مستوى اصابة الاوراق فى الخلف عمر ٢٨ مع ١٤ و ٢١ يوما بعد الظهور معنوية.

(ج) لم تكن الاختلافات معنوية فى مستوى اصابة اوراق الخلف بين عمر ١٤ و ٢١ يوما :

هذه النتائج تشير الى امكانية وجود اختلافات فى عامل او عوامل معينة ذات علاقة بتفضيل (Preference) الحشرة للتغذية على اوراق الخلف حسب اعمارها. او وجود اى آلية تضاد حيوى (Antibiotic mechanism) فيها. وهذا العامل مربوط بعمر الخلفة ويتناقص اثره مع الزيادة فى عمرها.

(٢) اثر فترة نضج الخلف واطوالها فى مستوى معدلات حياتها (Effects of tiller height and maturity period in their survival)

(أ) اوضحت النتائج اختلافات معنوية فى مستوى موت القمة النامية فى الخلف بين الاعمار المختلفة وبين العينات فى العمر الواحد.

(ب) دراسات الارتباط التى اجريت فى هذا الصدد تشير الى وجود اثر لعامل العمر على نسبة حياة الخلف معبرا عنه بنسبة موت القمة النامية فيها :

وفى ذلك ، الدلائل تشير على انه فى بداية عمر الخلف تكون ضخامتها (الاكثر طولا) هى العامل المهم فى مقاومتها للحشرة فى شكل موت قمة نامية. ولكن مع تقدم العمر ترتبط نسبة حياتها وبالتالى مقاومتها لافة ثاقبة الساق ،اكثر، بفترة نضوجها وتصبح الخلف الاسرع نضوجا هى الاكثر مقاومة للحشرة.

(ج) اتضح مرة اخرى ان العينة IS 25041 لها ايضا مقاومة فى الخلف وهى ليست مرتبطة بسرعة النضج من خلال اظهارها نسبة موت قمة نامية منخفض نسبيا بالرغم من انها متأخرة النضج.

(د) وضح من الدراسة ان الخلف تنضج اسرع من النبات الرئيسى فى نفس العينة :

تبدو اهمية ذلك فى عملية التوافق (Synchronization) الممكن حدوثه بين نضوج وتكوين القناديل (Heads) فى الساق الرئيسى و الخلف مما يسهل من عملية الحصاد ٠

(٣) معدلات نمو الخلف (Rate of tiller growth)

(أ) فى موسم الربيع كانت الاختلافات معنوية فقط عندما قيس نمو الخلف فى ٢٠ و ٢٤ يوم بعد ظهورها :

ربما يعزى ذلك للزيادة النسبية الملحوظة فى نمو خلف العينتين IS 19474 و IS 22806 فى تلك الفترة ٠

(ب) فى موسم الخريف اظهرت نفس العينتين مستويات نمو عالى للخلف مقارنة بالعينات الاخرى عندما تم تسجيله فى نباتات تم فيها حدوث موت قمة نامية٠

(ج) كانت نسبة موت القمة النامية فى خلف هاتين العينتين منخفضة نسبيا عندما اصيبت فى الاعمار ٢١ و ٢٨ يوم :

كل ذلك ربما يؤكد اهمية هذا العامل فى مقاومة الخلف للحشرة فى هذه

(د) كانت الاختلافات واسعة جدا بين معدلات نمو الخلف عندما قيست فى نباتات سليمة ومن نباتات مصابة حدث فيها موت قمة نامية :

عزى ذلك الى اثر السيادة القمية فى تثبيط نمو الخلف فى النباتات السليمة ٠ وفى الجانب الاخر، بحدوث موت القمة النامية تكون الحشرة قد تسببت فى رفع هذه السيادة موفرة بذلك فرصة اكبر لنمو الخلف٠

(هـ) تثبيط نمو الخلف بوجود البرعم القمى (Apical bud) تتضح عواقبه من خلال علاقة الارتباط السالبة بين طول الخلف عمر ٢٤ يوم فى النباتات السليمة ومستوى موت القمة النامية فى الخلف المصابة عمر ١٤ يوم فى موسم الخريف:

يرجع ذلك الى انه عندما اصيبت الخلف عمر ١٤ يوم فى هذا الموسم كانت لا تزال تحت تأثير السيادة القمية المفروضة من البرعم القمى آنذاك على اختلاف مستوى ذلك بين العينات ٠ أكثر من ذلك فان النتائج تشير الى أن

درجة الحرارة المرتفعة في موسم الخريف تساعد على تقوية هذا الاثر. وفي هذا الصدد حظيت العينتان IS 3492 و IS 9751 ، واللتان كانتا اكثرهم انتاجا للخلف، حظيتا باعلى معدلات نمو خلف فى النباتات السليمة حيث انعكس ذلك فى الانخفاض النسبى فى مستوى موت القمة النامية فى الخلف عمر ١٤ يوم.

من كل ذلك يتضح ان معدلات نمو الخلف كعامل يمكن ان يكون له اثره في مستوى اصابة القمة النامية بحشرة ثاقبة الساق يتوقف على وجود عينات تتمتع اصلا بهذه الخاصية (نمو الخلف السريع) وحالة النبات الفسيولوجية (نبات سليم ونبات حدث له موت القمة النامية). وحالة النبات الفسيولوجية ايضا متأثرة بموسم الزراعة (خريف او ربيع) حيث يكون اثر الحراره فى ذلك واضحا.

ثالثا : مصير الخلف تحت تأثير الاصابة بحشرة ثاقبة الساق

(Fate of tillers under stemborer infestation)

(١) اظهرت النتائج اصابة الخلف بالحشرة نفسها حتى فى حالة اصابة الساق الرئيسى فقط.

(٢) تكون الاصابة فى شكل موت قمة عادي او كسر للخلف (Tiller breakage) عادة ما يحدث فى اليافعة منها. كانت نسبة الخلف التى تعرضت للكسر فى موسم الربيع اكثر منه فى موسم الخريف.

(٣) تعرض جزء من الخلف للموت الطبيعي (Natural death) وذلك بواسطة ذبول الخلفة واصفرارها. وكانت الاختلافات فى ذلك بين المعاملات والعينات معنوية خصوصا بين مجموعة المقارنة والمعاملة المصابة. كانت نسبة الموت الطبيعى للخلف اكثر وضوحا فى موسم الخريف عنها فى موسم الربيع.

(٤) تعرض جزء قليل من الخلف للاصابة بذبابة الساق.

(٥) اما ما تبقى من العشيرة فقد كان اما خلفا منتجة (Effective tillers) أو غير منتجة (Immature tillers) :

نخلص من كل ذلك انه ليست كل الخلف تكون منتجة تحت تأثير الاصابة بحشرة ثاقبة الساق. وهنالك ايضا تأثيرات موسمية فى ذلك. ايضا يمكن أن يكون هنالك اثر لمستوى الاصابة في تحديد مصير الخلف.

رابعا : دراسة التأثيرات الموسمية فى عملية انتاج الخلف ومقدرة النبات على اظهار مقاومة التخليف

(Seasonal effects on tillering and recovery resistance to <u>Chilo partellus</u>)

لدراسة اثر الموسم فى العدد الكلى المنتج من الخلف والتعبير عن مقاومة التخليف تم تحليل احصائى مشترك لبيانات الموسمين الخاصة بذلك . ولتحديد أثر الموسم فى مقاومة التخليف استعملت نسبة مساهمة الخلف فى الانتاج الكلى للغلة كدليل لذلك. تم تحديد ذلك عن طريق حصاد الغلة للساق الرئيسى والخلف كل على حده . امكن ذلك بوضع بطاقة مميزة على النبات الرئيسى عن الخلف منذ البداية. كذلك حسبت نسبة النقصان فى انتاج الغلة فى العينات من جراء تأثير الحشرة واستعملت كدليل على مستوى القابلية للاصابة (Susceptibility) بالافة. وفى هذا الصدد اجريت دراسات ارتباط بين نسبة موت القمة النامية فى الساق الرئيسى ونسبة النقصان فى انتاج الغلة. (١) ظهرت اختلافات معنوية بين الموسمين فى العدد الكلى المنتج من الخلف.

(٢) كانت الاختلافات فى نسبة مساهمة الخلف فى الانتاج الكلى بين المعاملات وبين العينات معنوية فى الموسمين.

(٣) لقد كانت مساهمة الخلف فى الانتاج الكلى اكثر وضوحا فى موسم الربيع عنها فى موسم الخريف من خلال الاختلافات المعنوية بينهما :

لقد كانت الامكانية الكبيرة التى ظهرت فى العينات للتعويض (Compensation) فى موسم الربيع ، نتيجة لاثر درجة الحرارة المنخفضة فى النبات لحث (Induction) عدد اكثر من الخلف وبالتالى مقدرة اكبر للتعبير عن مقاومة التخليف.

(٤) من النتائج الهامة فى هذه الدراسة ، عدم ظهور علاقة ارتباط بين نسبة موت القمة النامية ونسبة النقصان فى انتاج العينات برغم وجود علاقة ارتباط سالبة فى هذا الصدد فى دراسات سابقة :

ذلك يوضح بجلاء اثر مقاومة التخليف فى اخفاء وتحوير هذه العلاقة . ايضا يعكس ذلك طبيعة العينات الداخلة فى هذه الدراسة ومعظمها عينات تقليدية غالبيتها يتصف بهذه الظاهرة فى حين ان معظم العينات المحسنة وبصورة خاصة الهجن (Hybrids) مثل الهجين الهندى CSH 1 تتصف بالضعف فى ظاهرة التخليف ، علاوة على ان البعض منها تم اختياره اساسا على عدم وجود هذه الصفة مثال الهجين الهندى CSH 5.

خامسا : تخليف مرتبط بفعل من الحشرة نفسها

(Insect-Induced tillering)

واخيرا لمعرفة ما اذا كان هنالك درو للحشرة نفسها فى عمـــلية التخليف ، اجريت تجربة صغيرة في الاصص البلاستيكية خارج البيوت الزجاجية وكانت معاملاتها كالاتى : (أ) ترك النبات بدون اصابة (المقارنة)،(ب) اصابـة النبات عن طريق استعمال اقفاص (Stem cage) صغيرة لحصر اليرقات حـول الساق و (ج) حث ظهور الخلف ميكانيكيا عن طريق تحطيم القمة الناميــة بواسطة ابرة معدنية صممت خصيصا لهذا الغرض • كذلك تم اختيار عينـات عرفت بانها لا تنتج او ضعيفة فى انتاج الخلف قبل حدوث موت القمـة•

(١) كشفت النتائج من هذه الدراسة عن وجود اختلافات معنويـة بين عدد الخلف المنتج من جراء فعل الحشرة والعدد المنتج مـن جراء التحطيم الميكانيكى للقمة النامية•

(٢) بعض النباتات المصابة بالحشرة استجابت قبل حدوث مـوت القمة فى شكل ظهور بعض الخلف او تحسن فى مستوى نموها فـى بعض الحالات•

الخلاصـة العامـة :

هذه النتيجة الاخيرة مع النتائج السابقة تشير الى ان مقاومـة التخليف يمكن ان تكون محصلة لعدة عوامل هى : مقدرة تخليفية موجـودة اصلا فى النبات او العينة بالاضافة الى خصائص نباتية فى الخلف (سـرعة معدلات نموها ونضجها) وتأثيرات بيئية (الحرارة) ثم تأثير قد يكون مـن الحشرة نفسها تصحبه استجابة من النبات فى اتجاه زيادة في عدد الخلـف وارتفاع فى مقدراتها الحياتيـة•

INTRODUCTION

The geometric increase in world population continues to demand greater production of staple cereal crops. _Sorghum bicolor_(L.) Moench, the grain sorghum, ranks fifth in acreage and production among the world's major cereal crops following wheat, rice, corn, and barley (Young and Teetes, 1977). Potential grain yields of sorghum are similar to those of other important cereals. Yields of 16,500 and 14,250 Kg/h having been reported by Pickett and Fredericks (1959) and Fischer and Wilson (1975), respectively. Average world-wide yields are nearer to 1300 Kg/h, ranging from as low as 660 Kg/h in parts of Africa to as high as 4000 Kg/ha in Latin America. Although sorghum is an important food and feed crop, especially for subsistence farmers in the semi-arid tropics, grain yields are generally low, ranging from 600 to 800 Kg/h.

Insect pests are one of the major yield-reducing factors in sorghum, which is nearly attacked by 150 insect pests species (Reddy and Davies, 1979 and Jotwani _et al._, 1980). A number of stem borer species are serious sorghum pests, attacking at various growth stages. The species spectrum varies from region to region. _Chilo partellus_ Swinhoe, commonly known as the maize stem borer or the spotted stalk borer, is one of the serious pests of sorghum in the lowlands of East Africa (Ingram, 1958) and India (Jotwani and Young, 1972), and is potentially important in other areas of the semi-arid tropics. Although _C. partellus_ occupies the low warm and humid areas of sorghum production, it has been recorded at an altitude of 1800 m (Seshu Reddy, 1989).

It first appeared in East Africa in the early 1950's and has now spread as far as Northern Sudan, Botswana and Zaire (Ingram, 1983) and may have spread westward from the Sudan to West Africa. Also it extends as far East as Australia (Appen. A).

In the Sudan the three crops sorghum, millet, and wheat account for about 98% of the total cereals consumed as human food. Sorghum alone contributes about 63% of this amount. The total area under this crop in the Sudan is estimated at 5.883, 3.801, and 2.925 million h in the years 1988, 1989, and 1990, respectively (FAO Year book, 1991). About 92% of the area under sorghum cultivation is in the mechanized and traditional rain-fed areas, while the remaining 8% is in the irrigated sector. Sorghum is the main staple food for millions of people in the country. In many parts, the crop is wholly utilized. The grain is used for making "Kisra" (unleavened bread from fermented dough), a significant portion is also used as thick porridge, "Asida", as a popular beverage "Abreih",and as a local drink "Marisa". The stalks are used as building material and straw is used as animal feed or as fuel. Sorghum is thus the nutritional backbone of the country.

Generally, sorghum yields in the Sudan are very low (Appen. B) and vary according to season and cultivation system. Several factors are held responsible for this low productivity, one of which is insect pests. Among insect pests, lepidopterous stem borers are the most important. Several species are involved, namely C. partellus, Sesamia cretica (Lederer), and Busseola fusca (Fuller). The pyralid, C. partellus is the most destructive and it is widely distributed in the Sudan. It has been reported from the Northern region, Khartoum, Gezira, Blue Nile, Kassla, and Equatoria (Nasr Eldin, 1965; Anonymous, 1969; and Siddig, 1972). In the irrigated Gezira, infestation by stem borers in season 1981/82 has exceeded 50% (Anonymous, 1982).

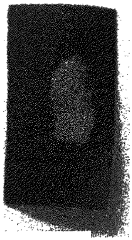
Life cycle of stem borers includes egg, larva, pupa, and adult (Plate 1A). Damage results from larval feeding and may take one or a combination of leaf-feeding, deadheart formation, stem tunneling, stem and peduncle breakage, and chaffy heads (heads without seeds). Since C. partellus is an internal feeder, it is little affected by predators and parasites, unfavorable environmental conditions or insecticides. The common approach to the control of C. partellus in the Sudan has been largely through the implementation of cultural practices such as sowing date. Chemical control is not common in the Sudan due to cost and cash returns from sorghum. With the current emphasis in Sudanese agriculture directed towards increasing food production, a transition is taking place towards more and intensive sorghum production. Improved and intensive cultivation will increase the relative importance of insect pests. In this situation, control measures will become a necessity to ensure maximum returns from increased agricultural inputs. However, the limitations of each control method indicate that host-plant resistance and cultural practices should be major components in the integrated management of sorghum stem borers (Nwanze and Mueller, 1989). Kambal (1977) noted that breeding for resistance against pests and diseases, particularly Striga, stem borers, and shoot fly is one of the aspects of sorghum research in the Sudan worthy of special attention and integrated efforts.

Host-plant resistance is economic, efficient, enviromentally safe, and offers a long-term solution to managing stem borers and other sorghum insect pests. Well over 100 insect resistant crop cultivars are grown in the United States, and probably twice that many are cultivated in other major crop production areas of the world. Over one-half of the cultivars developed are those of the major cereal grain food crops namely, maize, sorghum, and wheat (Smith, 1989). However, sorghum is the most leading in this respect.

All three types of mechanisms of resistance defined by Painter (1951), i.e. non-preference, antibiosis, and tolerance have been observed in sorghum resistant to C. partellus. Dead-heart formation is considered the most stable criterion for differentiating the degrees of resistance (i.e.primary resistance; Singh et al., 1968). Taneja and Leüschner (1985) observed highly significant and negative relationship between number of deadhearts and grain yield of sorghum. However, levels of resistance to stem borers are highly variable over space and time. Generally, low to moderate levels of resistance are available to deadheart formation and peduncle damage. Leaf-feeding and stem tunneling, the other two parameters used for measuring borer resistance, are not correlated with reduction in grain yield (Taneja and Nwanze, 1989). Some varieties tiller after the main stem is killed and produce a crop; this is known as recovery resistance or secondary resistance (House, 1985). However, sorghum plant is a typical grass, which is often grown in cultivation as a single-stemmed type, but which shows great variation in tillering capacity determined by both variety and plant population. Some varieties tiller early, while others do not tiller untill after flowering except as a response to damage (Doggett, 1988). Some Indian hybrids (e.g. CSH 5, CSH 8) have been selected specifically for lack of tillering and, hence poor recovery resistance is expected. However, several local cultivars and landraces exhibit a high tillering ability, and tillering as an aspect of varietal tolerance at low borer infestation, may result in an overall increase in head production (Harris, 1962).

Agronomically the main interest focuses on basal tillers (Plate 1B) which arise from the growth of buds at the lower nodes. The ability of these tillers to withstand any subsequent reinfestation by stem borer is very essential and this obviously contributes a major part in the mechanism of recovery resistance. Rapid growth and development of tillers will also provide a better chance for synchronization with main stem development and head production in healthy plants. It should also be emphasized that tillering capacity is genetically controlled, though it is affected by environmental factors such as temperature (Downes, 1968). Extra tillers may be induced by feeding activity of the insect. This indicates the possibility of different expression of recovery resistance in response to different environmental or seasonal influences.

There is an apparent lack of information on the interaction between environmental factors and _C. partellus_ damage on tiller production and recovery resistance in sorghum genotypes. This



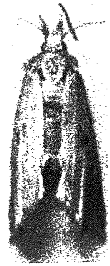


Plate 1A. Life cyle of C. partellus.

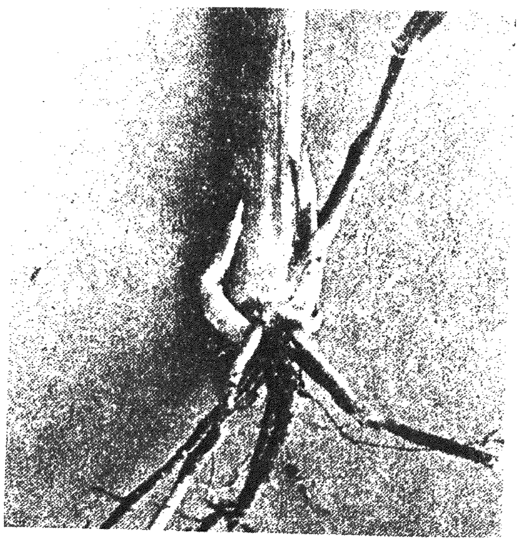


Plate 1B. Basal tillers [(Source: House, 1985). The photo used after permission of the author].

study was therefore conducted with the following objectives:

1. To study time and pattern of tiller appearance in sorghum genotypes in relation to *C. partellus* infestation and damage.
2. To relate tiller growth and development with resistance/ tolerance to *C. partellus*.
3. To study tillering performance and fate of tillers under stem borer infestation.
4. To investigate seasonal effects on tillering and recovery resistance under *Chilo* infestation.

LITERATURE REVIEW

BIOLOGY OF *Chilo partellus* SWINHOE

The biology of *C. partellus* is well documented in Eastern Africa and India (Rahman, 1944; Trehan and Butani, 1949; Nasr Eldin, 1965; Seshu Reddy, 1969; Gahukar and Jotwani, 1980; and Alghali, 1985). Ovipositing females lay their eggs in masses of 10-80 on the undersurface of leaves, often near the midrib. The eggs are flattened, oval, and tend to overlap like fish scales.

Eggs hatch in about 4-6 days. The larval stage is mostly spent in the leaf whorls and stems and lasts for 2-3 weeks. Pupation takes place in the stems or in the soil and adults emerge one week later. Thus, the insect completes its life cycle in one month with 3-4 overlapping generations in a crop season and two generations can attack the same crop.

CROP DAMAGE IN RELATION TO BEHAVIOR AND LIFE CYCLE

In a recent review Leüschner (1989) described the relationship between crop damage and the life cycle of *C. partellus*. Usually the first egg masses are found on sorghum seedlings at 10-15 days after seedling emergence (DAE). The first-instar larvae migrate from the oviposition site (leaf undersurface) to the whorl. This is an upward movement of *Chilo* larvae which has been shown to result from positive phototaxis (Bernays *el al.* 1983 and 1985). The larvae then feed on the young and tender leaves near the base of the whorl. Feeding activity continues in the whorl until the second and third instars. At this stage they stop feeding, leave the whorl, and migrate to the base of the seedling where they bore into the seedling base a few centimeters above soil level (Fig. 1A). Depending on temperature, entry into the stem takes place about 8-10 days after hatching. Feeding at the base of the seedling may result in two symptoms, depending on the point of larval entry in relation to the growing point: if the point of larval entry coincides with the position of the apical meristem, the latter is destroyed giving rise to deadheart (Fig. 1A and 1B). However, if floral initiation has taken place and the apical meristem has moved upward, larvae may feed only on the initial stem resulting only in stem tunneling (Fig.1B). If no deadheart is formed, the larvae continue to tunnel below the growing point until pupation. This activity weakens the plant, making it susceptible to wind breakage. Infestation by second generation moths usually occurs between 45-55 DAE. After feeding within the whorl, the second and third-instar larvae move one or two internodes below the whorl (not to the base), and penetrate into the stem usually at the leaf axis (Fig. 1C). In this case, stem tunneling, peduncle breakage, incomplete grainfill and partial or complete chaffiness of the head may be observed.

HOST PLANTS

The main cultivated hosts of C. partellus are sorghum; maize; pearl, foxtail and finger millets; sugar cane and rice (Harris, 1989). Several wild grass hosts were found to harbor larvae of C. partellus (Seshu Reddy, 1989).

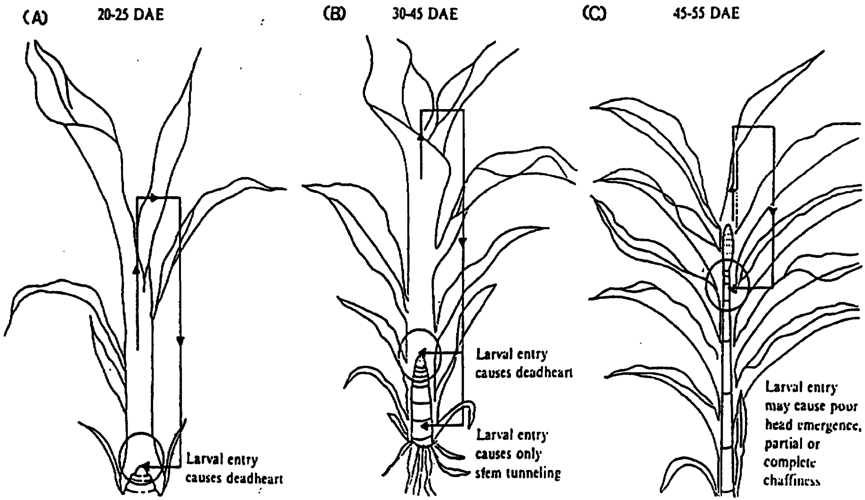


Figure 1. Larval movement and entry points in relation to plant growth stages: (A) before panicle initiation, (B) after panicle initiation, and (C) flag leaf stage. (Source: Leuschner, 1989).

CONTROL METHODS

The four most widely applicable pest control methods are chemical, biological, cultural, and varietal resistance.

Chemical control of stem borers usually involves soil furrow applicaton, seed treatment, foliar sprays and dusts, and leaf whorl placement of insecticides (Kishore, 1989). Among the chemicals used are DDT, endrin, lindane, BHC, endosulfan, parathion, malathion, carbofuran, and aldicarb. The ecological effects of insecticides application have been summarized by Metcalf (1986). Joyce (1955) and Eveleens (1983) have also pointed out the crisis and the entomological problems arising from chemical sprays of cotton insect pests in the Sudan.

A number of parasites and predators of stem borers have been recorded (Rao, 1964; Sharma *et al.*, 1966; Greathead, 1971; Van Rensburg and Van Hamburg, 1975; Jotwani *et al.*, 1978; AICSIP, 1986-87; and Skoroszewski and Van Hamburg, 1987). The egg and larval parasites, *Trichogramma sp* and *Apanteles sp* were found to be successful in controlling *C. partellus* in sorghum. The contribution of spiders, ants, lady bird beetle, and earwigs in controlling *C.partellus* population have also been reported (Sharma and Sarup, 1979 and Seshu Reddy, 1983). Pathogenic microbes such as fungi, protozoa, and nematodes were found to attack *C. partellus* (Sinha and Parasad, 1975, and Seshu Reddy, 1989).

The main cultural practices used against stem borers are: tillage and mulching, time of planting, spacing, fertilizer and water management, crop sanitation, removal of deadhearts, volunteer and alternative host plants, and intercropping (Seshu Reddy, 1985).

The planting of agronomically improved varieties with natural resistance to pests now forms the foundation of many pest management programs. Luginbill (1969) indicated that the ideal method of combating insects that attack plants is to grow insect-resistant cultivars. The use of varietal resistance may be the principal control method or an adjunct to other control measures (Painter, 1951). Kogan (1982) listed the followings among the most desirable features of plant resistance from the broader ecological view point: (a) specificity, (b) cumulative effectiveness, (c) persistence, (d) harmony with the environment, (e) ease of adoption (resistant varieties once developed can be easily incorporated into normal farm operations at little or no extra cost), and (f) compatibility with other pest management tactics.

HOST-PLANT RESISTANCE

Plant Resistance to Insects: General Aspects

Plant resistance can be defined as "the relative amount of heritable qualities possessed by the plant which influence the ultimate degree of damage done by the insect in the field" (Painter, 1951). Beck (1965) defined resistance as the collective heritable characteristics by which a plant species, race, clone, or individual may reduce the probability of successful utilization of that plant as a host by an insect species, race, biotype or individual.

Cultivars differ in degrees of resistance, there may be a gradation from extreme resistance to extreme susceptibility (Russel, 1978). Resistance is classified as low, moderate or intermediate, or high.

Painter (1951 and 1958) classified plant resistance into three mechanisms: non-preference, antibiosis, and tolerance. The term 'non-preference' refers to a behavioral response of the insect to a plant, whereas 'antibiosis' and tolerance refer to plant characteristics.

Non-preference is expressed in response to the insect in the use of its host for oviposition, food, and/or shelter. Kogan and Ortman (1978) suggested the term 'antixenosis' to describe the plant properties which are responsible for non-preference.

Antibiosis relates to the adverse effects of the host plant on the biology of the insect (e.g., mortality of larvae, smaller insect, longer development time, etc.) when resistant plant is used for food.

Tolerance describes a plant or cultivar that is able to grow and reproduce, repair injury or compensate, or recover from damage to a marked degree inspite of supporting an insect population that damages a susceptible plant or cultivar. Since a high degree of tolerance would increase the economic density threshold, this mechanism could play an important role in integrated insect control (Dahms, 1972).

There are types of apparant resistance, not heritable, which should not be confused with true resistance. Painter (1951) used 'pseudoresistance' to describe resistance due to transitory characters in potentially susceptible plants. The types he listed are (a) host evasion, in which the host plant passes through the susceptible stage quickly or when insect populations are low; (b) escape, in which a particular host plant is neither infested nor injured despite the local presence of the insect pest; and (c) induced resistance, in which some environmental conditions, such as soil fertility, temporarily increase the level of resistance.

Screening For Resistance to *C. partellus*

The earliest report on sorghum varieties resistant to *C. partellus* was by Trehan and Butani (1949). Pant *et al.* (1961) and Swarup and Chaugale (1962) later reported some differences in damage due to the stem borer in different varieties of sorghum.

A systematic screening of the world sorghum collection against the spotted stem borer was started in 1962 in India under the cooperative efforts of the Accelerated Hybrid Sorghum Project, the Entomology Division of the Indian Agricultural Research Institute, and the Rockefeller Foundation (Singh *et al.*, 1968; Pradhan, 1971 and Jotwani, 1978). This work has been continued by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the All India Coordinated Sorghum Improvement Project (AICSIP). A number of stem borer resistant sorghum genotypes have been identified by various workers in India and elsewhere (Singh *et al.*, 1968; Jotwani *et al.* 1974; Kundu and Jotwani, 1977; Jotwani *et al.*, 1979; Singh *et al.*, 1980; Jotwani, 1982; Dalvi *et al.*, 1983; Singh *et al.*, 1983; Sharma *et al.*, 1983 and Taneja and Leüschnar, 1985).

Large scale screening of sorghum genotypes using natural and artificial infestation has been undertaken at ICRISAT Center in India. Over 12,000 accessions have been evaluated for resistance to *C. partellus* and 61 lines have been reported to be resistant. In addition, selections from 9,000 germplasm lines are under various stages of testing (Taneja, 1987).

Sudan is believed to be one of the primary centers of origin and diversity of sorghum (Harlan, 1971). Leppik (1970) proposed that the search for insect resistance should be conducted in the original home of the insect and plant, although there are several cases where resistance has been obtained outside the geographic center of origin (Smith, 1989). Around 1500 germplasm accessions have been collected by ICRISAT from different locations in the Sudan (Mengesha and Prasada Rao, 1982). Five sources of resistance to *C. partellus* were identified from this collection (Taneja and Leüschner, 1985).

Mechanisms of Resistance to *C. partellus*

Non-preference

Ovipositional non-preference, as a mechanism of *C. partellus* resistance in sorghum, has been reported on some resistant genotypes by many workers in India and eastern Africa (Lal and Pant, 1980a; Dabrowski and Nyangiri, 1983; Dabrowski and Kidiavai, 1983; Singh and Rana, 1984; Alghali, 1985; and Taneja and Woodhed, 1989).

Lal and Pant (1980b) noticed wide differences in the ovipositional behavior of *C. partellus* on resistant and suscepitable varieties of maize and sorghum in the laboratory. They found that susceptible varieties were preferred for the establishment of populations, indicating the possible preference of some volatile chemical factor in the foliage either repelling or attracting the adults.

Dabarowski and Nyangiri (1983) found significant differences in the number of *Chilo* eggs laid on three maize inbred lines tested in choice and non-choice situations.

In a field trial on ovipositional preference of *C.partellus* in a set of 20 sorghum genotypes, Taneja and Woodhead (1989) found that the total number of egg masses was significantly higher, i.e. 25 and 41 egg masses per 50 plants on the susceptible genotypes ICSV 1 and CSH 1, respectively, compared to 2-3 egg masses per 50 plants in the resistant ones (e.g. IS 2309 and IS 5538).

Antibiosis

In experiments conducted under controlled laboratory conditions by Kalode and Pant (1967a) on the effect of host plants, viz. sorghum, maize,and pearl millet, on the larvae of *Chilo zonellus*, the results indicated that maize was more suitable as food than sorghum and pearl millet. In sorghum, three varieties were found to exhibit antibiosis. The larval survival in these ranging from 24.4 to 36.7 percent as against 40-71.1 percent in the susceptible varieties. Some larvae failed to pupate and remained in the larval stage.

Sharma and Chatteji (1971a) carried out cage studies on antibiosis to *C. zonellus* in different maize germplasms and found that germplasms with less vigorous plants showed more antibiosis as compared to the susceptible germplasm. They also conducted laboratory tests which showed great variation in survival and development of *C. partellus* on 11 differernt lines of maize. Studies by Jotwani *et al.* (1978) also showed higher mortality in the early larval stage of *C. partellus* in resistant varieties, than in the susceptible CSH 1.

Taneja and Woodhead (1989) conducted a study on the effect of 20 sorghum genotypes on the biology of *C. partellus*, using black-head stage eggs to infest plants 15-20 days after crop emergence. They found significant differences with respect to first instar larval establishment in the whorl, time interval between hatching and larval boring into the stem, larval mass, and survival rate. A lesser proportion of larvae (25-40%) became established in the whorl of resistant genotypes (e.g. IS 12308, IS 13100, and IS 22269) compared to 51% in the susceptible genotype, ICSV 1.

Tolerance

Jotwani (1978) reported some tolerant sorghum genotypes with lower yield loss due to stem borer infestation and attributed this to tolerance mechanism. In spite of severe leaf injury and stem tunneling, the final plant stand was very good and most of the plants had normal-sized earheads.

Dabrowski and Kidiavai (1983) conducted field observation on *Chilo* infestation of 100 promising sorghum lines. They recorded tolerance in some lines to leaf damage and to larval feeding in stems.

Factors Associated With Resistance to C. partellus

Physical plant characters

Kumar and Bhatnagar (1962) found that dwarf and early sorghum varieties with short and thin stems; few, narrow and short leaves; short and thin earheads; less grain weight and threshing percentage; white exposed seeds; spreading earheads and juicy stems were more resistant to *C. partellus* than others.

Leaves with distinct midribs (in mature maize) or with elongate creases (in dry sorghum) offer concave areas in which egg batches can be placed. Such leaves were favored for oviposition. Surfaces with minor irregularities such as hairs, were not favored (Roome *et al.*,1977).

Durbey and Sarup (1982) and Dabrowski and Nyangiri (1983), related trichome density to oviposition nonpreference. Bernays *et al.* (1983) found that there was no correlation between climbing speed of *C. partellus* and trichome density in sorghum. They found that the white bloom of epicuticular wax developed by sorghum plants retards the climbing by *Chilo*.

The larval duration on the sorghum stem was positively correlated with plant height and number of internodes per plant, but negatively correlated with peduncle length. Larval mortality on the stem was positively correlated with plant height, but negatively correlated with peduncle length. Pupal weights on stem showed positive association with peduncle length and negative association with plant height and number of internodes per plant

Ampofo (1985), in Kenya, found that in some maize genotypes the lower surfaces were preferred on all leaves by C. partellus. He concluded that exudates from plants of one maize genotype increased oviposition, while exudates from other genotypes depressed oviposition. Exudates from all genotypes shortened moth longevity, compared to distilled water. Fertility was not influenced by the source of moth diet.

Woodhead and Taneja (1987) pointed out that the physical plant resistance characters correlated well with larval establishment of C. partellus on 20 sorghum genotypes. These characters were: orientation of leaf to stem (a small angle between leaf and stem, i.e. upright leaves) affected the insect's ability to reach the whorl, elongated internodal length between leaves three and four, curbing of leaf base (with respect to accommodation of first instar larvae), and detachment of the leaf sheath from the culm. The only physical character common to all resistant genotypes was found to be erect and narrow leaves.

Plant growth parameters

Taneja and Woodhead (1989) found that early panicle initiation and rapid internode elongation are associated with resistance to C. partellus in sorghum. In resistant genotypes, these factors were reflected in: (a) the success of first instar establishment in the leaf whorl, (b) the interval between hatching and larvae boring in the stem, (c) larval mass, and (d) survival rate. They observed that genotypes with early panicle initiation escaped deadheart formation due to inability of larvae to reach the growing point which would already have pushed up above larval entry point. Shoot length, i.e. faster internode elongation, was another significant growth characteristic in stem borer resistance. This characteristic also pushes the growing point upward, hampering the ability of the boring larvae to reach it and, thus preventing deadheart formation.

Anatomical factors

Kausalya (1989) conducted field trials using Chilo resistant and susceptible genotypes to study the anatomical variations and effect of larval feeding on various tissues of stem and peduncle. The effect of larval feeding on stem and peduncle tissue was generally similar in resistant and susceptible genotypes. However, in stems of Maldani and ICSV 445 and in the peduncles of ICSV 700 and ICSV 445, the vascular bundles were normal and did not exhibit any browning, which normally results from feeding of C. partellus. This indicates resistance reaction.

Chemical and biochemical factors

Low sugar content (Swarup and Chaugale, 1962), amino acids, total surgars, tanins, total phenols, neutral detergent fibre (NDF), acid detergent fibre (ADF), lignins (Khurana and Verma 1982, 1983), and high silica content (Narwal, 1973) have all been reported to be associated with stem borer resistance.

Factors related to larval establishment and dispersal

The establishment and survival of larvae of C. partellus and the extent to which larvae successfully reached the whorls of different sorghum genotypes have been extensively investigated by many workers. Bernays et al. (1983) found differences in the extent to which larvae of C. partellus successfully reached the whorls of the two sorghum cultivars, i.e. IS 1151 and IS 2205. Climbing rate of the larvae increased with temperature and was greater on large plants than small ones.

Woodhead et al (1983) in field studies found that the initial establishment of C. partellus larvae on sorghum is more important in determining overall survival; establishment was determined by the relative success of the larvae in reaching the whorl.

Ampofo (1986) found that the dispersal of C. partellus larvae increased 2-fold when plants of the cultivar ICM2-CM (resistant) were surrounded by plants of the susceptible Inbred A, and decreased when Inbred A plants were surrounded by the resistant one.

RECOVERY RESISTANCE

The Mechanism and the Prospectives

Doggett (1988) reported a completely different secondary resistance to shoot fly and referred to it as 'recovery resistance'. Closer to the equator, with no really cool temperatures and in areas of sufficient rainfall, sorghums may also be in the field for most of the year and are often ratooned. In Lango, Uganda, the ratoon harvest may be the main crop. In Buganda, cultivars such as Namatare and Serena which are susceptible to shoot fly at levels similar to susceptible CK 60 respond by tillering. The tillers are scarcely affected by shoot fly, and grow to give good grain yield. This is presumably because they were developed under conditions where shoot fly attack was very common and these cultivars were used successfully as parents in breeding programs to develop resistant lines (Doggett et al., 1970 and Stark, 1970).

Under good growing conditions, sorghum can produce satisfactory grain yield while harboring large borer populations. Tillering and branching of the stems compensate for main stems which have been damaged by borer, especially when the conducting tissues have been cut. Under difficult growing conditions or under periods of stress, tolerance and recovery of sorghums after borer attack may be much reduced with consequent large losses of grain yield (Doggett, 1988).

In India selection program for recovery resistance in sorghum to shoot fly has also been carried out (Vidyabhushanam, 1972). In this program only plants that produce 2,3 or more tillers with respectable heads that mature within 10 days of the time of maturity of the original plant, were considered. Adequate space (20 to 40 cm. between plants in the row) has been given to reduce plant competition and allow full tiller expression. The variety Serena was used as standard in the good side and CK-60 as a shoot fly-susceptible check.

Doggett (1972) also noted that under conditions where the rains are of short duration, primary resistance may be the only effective form, since there may not be time for the recovery resistance to operate properly before soil moisture dries out. Vidyabhushanam (1972) indicated the need to combine recovery resistance with other mechanisms. A number of indian varieties selected for their primary resistance to shoot fly have shown good recovery resistance under Uganda conditions (Barry, 1971).

Tillering in Sorghum

De Wet and Schechter (1977) listed the reduction in tillering capacity as one of the major morphological changes associated with domestication in sorghum. The human influence on plant evolution as a consequence of agricultural practices is reflected in this domestication. Improvement of the desired product frequently involved the intentional reduction of factors that coincidently were involved in the mechanisms of resistance (Baker, 1972).

Point of initiation and time of appearance of early tillers

Escalada and Pluknett (1975a) conducted a pot study to understand the basic growth patterns and tillering behavior of sorghum from main crop to succeeding ratoon crop. Their results showed that in the main crop, early tillers originated from basal nodes. As the plant grew and epigeal nodes were produced, tillers arose either from basal or epigeal nodes .

Appearance of early tillers was affected by plant population and occurred sooner in low than in a high plant population. Tillers were produced by plants in rapid sequence. Within hybrids, the time difference in the production of the first few tillers was not so much, but as tillering continued the time gap became wider.

In the first and second ratoon, production of tillers among hybrids at different plant populations was rapid. Six to nine days after harvest, tillers appeared mainly from the the basal portions of the stubble. Tillers that developed later usually originated from the epigeal nodes. All tillers appeared before heading.

Fate of tillers

Escalada and Plucknett (1975a) found that not all tillers that developed in the main crop and ratoon crops reached maturity. In most cases the first two tillers died. It took 21 to 65 days after emergence for the two early tillers to die in the main crop while in the ratoon crops, it took 7 to 22 days. Death of early tillers was attributed to the growth and develpoment of parent shoot, which can not fully support the tillers without injuring itself. Milthorpe and Davidson (1966) assumed that part of the dry matter accumulating in the tiller is derived from the parent shoot and is not the product of photosynthesis of its own leaves. Williams (1966) found that young fully expanded leaves translocate assimilates to young tillers in the axils of older leaves. This indicates that tillers that appear before the parent shoot become well established will either die or be retarded in growth. Tillers that develop when the parent shoot can support them reach maturity and produce heads. Food manufactured during the reproductive stage is utilized predominantly in grain-filling; hence available nutrients are inadequate to support normal growth and development of late tillers (Escalada and Plucknett, 1975a).

Tillers that were produced on the upper parts of the stuble or axillary tillers (Plucknett et al., 1984), usually were not productive because they were more susceptible to breakage. These high tillers also had week root systems which were made up of adventitious or aerial roots.

Attack of tillers by insects has also been reported (Blum 1963; Nye 1960, and Swaine and Wyatt, 1954). Small seedlings of sorghum may be killed by shoot fly, while larger seedlings continue to produce tillers, which may in turn be attacked. Delayed tillers may escape shoot fly .

Physiological aspects of tillering

Wilson and Eastin (1982) noted that there must be physiological factors determining the occurrance of tillering and its consequences for yield, but little is known about either.

Mitchell (1970) found that after a plant has been partially or completely defoliated, carbohydrates reserve materials are used in the following order: new leaf growth, restoration of carbohydrates reserves, root growth, and finally tillering. Tillering occurs only after the needs of the main shoot have been met or when it loses apical dominance.

With the death of the main stem (apical bud) as a result of

C. partellus infestation, apical dominance is removed, and a number of tillers form (usually two; Leüschner, 1989). Phillips (1975) reviewd the work done on apical dominance. The primary hormonal correlative signal in the inhibition of lateral buds by the apical bud appears to be auxin derived from young growing leaves. There is very little evidence that the other classes of known plant growth hormones, cytokinins and abscisic acid, operate as correlative signals in apical dominance. On the other hand, there are numerous data indicating that cytokinins are essential for lateral bud outgrowth. Also, the angles at which branches and leaves are borne to the stem appear to be regulated by activities of the apical bud or dominant shoot.

Genetics of tillering

Genetic variation has also been examined and this has been comprehensively reviewed by Quinby *et al.* (1973). Uniform tillering "tu" is recessive to delayed tillering, and tillering "Tx" is dominant to a single stalk. Both of these were identified in Sudan grass (Ayyanger and Ponnaiya, 1939c). Hybrids produced more tillers than their parents (Karper and Quinby, 1973; and Quinby, 1963). Kambal and Webster (1966) and Beil and Atkins (1967) found little difference in the amount of tillering between parents and hybrids. However, Haensel *et al.* (1963), Webster (1965) and Kullaiswamy and Goud (1982a) reported that non-tillering was dominant over tillering.

Studies by Prabhakar and Goud (1987) showed that two duplicate genes were involved in the expression of tillering habit as evidenced by a 15:1 ratio with tillering habit being dominant.

The plant type of Webster (1965)"tl" for recessive tillering is a biological oddity, a product of irradiation (Doggett, 1988).

High heritability in sorghum for recovery resistance to shoot fly, as well as a high genetic correlation between recovered plants and yield were reported (Doggett _et al._, 1970, and Starks _et al._, 1970).

Tillering and environmental factors

Although environmental conditions have limited effects in the initiation of tillers, they have a marked influence on subsequent tiller development (Evans, Wardlaw, and Williams, 1964). Environmental factors including temperature, photoperiod, light intensity, soil moisture, and fertility have been reported to affect the number of tillers produced by sorghum and other grasses (Gerik and Neely, 1987).

Temperature and photoperiod. Downes (1968) found that in cv. Combine kafir the basal buds did not expand into tillers when the daily mean temperature exceeded a threshold value of about 18 ^{o}C, and that below this temperature tillering began at the four to six leaf stage. Tiller number was increased from three to eight when temperatures were reduced to 13/8 ^{o}C (day/night; Major _et al._, 1982).

Myers _et al._ (1986) found that tiller number in some sorghum cultivars was significantly correlated with the inverse of mean temperature between emergence and floral initiation (r=0.481). Downes (1968) suggested that higher temperatures may have been suppressive because of promotion of leaf expansion and hence competitive use of assimilate in the leaves.

Escalada and Plucknett (1975b) showed that there was a considerable interaction between the effects of temperature and photoperiod on tillering. With low temperature (23.9 °C-day/15.5 °C-night) and short day (10 hr), fewer tillers/plant were produced resulting in the development of fewer reproductive tillers. At the same low night and day temperatures, but photoperiod increased from 10 to 14 hrs, more tillers/plant were produced with more reproductive tillers. When temperatures were increased (from 23.9/15.5 °C to 32/23.9 °C) with a simultaneous increase in daylength (10 to 14h), tiller number per plant increased. Warrington et al. (1978) noted that it is possible that this increase was simply due to a higher radiation recipient, but the result appears to conflict with that of Shamsuddin (1967) who showed clearly that sorghum produced more tillers in short days.

Plant population. Escalada and Plucknett (1975a) also showed that high plant populations delay the production and number of tillers. This observation has been confirmed by a series of experiments in Botswana (Peacock and Wilson, 1984). Also in studies on the effect of plant population on tillering of sorghum, Schulze (1971) found that tillering occurred at the low populations and decreased as populations increased to a density of approximately 20 plants per square meter. However, tillering ceased for all the genotypes used except Mini-Milo-50, which has a very strong tillering ability. This tillering which increases the number of panicles per unit area was considered to be partly responsible for lessening the effect of plant population (Grimes and Musick, 1960; Stickler and Laude, 1960, Stickler and Wearden,1965). In this case, tillering can contribute significantly to the total yield (Karachi and Rudich, 1966) and compensate in the direction of higher plant population if more favorable conditions occur (Clegg, 1972). Perhaps the reduction in tillering at high population densities arises from light competition and reduced assimilate supply (Wilson and Eastin, 1982).

Effect of nitrogen. Escalada and Plucknett (1977) studied the performance of ratoon crops of grain sorghum (Pride 550 Br), as affected by four nitrogen rates, i.e. 0, 100, 200, and 250 Kg N/ha as urea, and three cutting heights 3, 8, and 13 cm) in the field in Hawaii. They found that in the plant and ratoon crops, more tillers, larger leaf area, larger stalk, larger heads with more heavier grains, and taller plants, and therefore increased grain and stover yields were produced with higher nitrogen treatments up to 250 kg/ha. During winter, highest yields were produced with 200 or 250 kg/ha and when plants were at the 13 cm cutting height. In summer, higher yields were produced with the same N rates but lower cutting heights (3 and 8 cm).

Glyphosate-induced tillering. Baur (1979) found that application of sublethal doses of glyphosate (a herbicide) in the partially furled third true leaf of 30-day-old sorghum seedlings induced basal stem swelling and bud release. This implies that tolerance may be obtained through the induction of tillering of grasses by growth regulators (Kogan and Paxton, 1983). Combining glyphosate with cycloheximide, a cytokinin or L-phenylalanine significantly reduced the incidence of basal stem swelling. No such reductions were observed when indole-3-acetic acid (an auxin) or L-tyrosine was combined with glyphosate.

Herbivore-induced tillering. Stimulation (or inhibition) of compensatory mechanisms, an interesting effect of herbivore feeding on plants, has been observed by several authors comparing hand defoliation with herbivory in grasses.

Some workers also reported that the regrowth of grasses is stimulated by growth-regulator-type compounds in the saliva of ruminants (Kogan and Paxton, 1983). However, regrowth seems to be inhibited in grasses by grasshopper salivary gland and gut extracts at high defoliation levels, but it was apparently stimulated at low levels (Capinera and Roltsch, 1980). When 1/3 defoliation was implemented by actual feeding by grasshoppers on wheat, there was a substantial increase in the number of tillers. Tillering was much less in hand defoliated plants. However, when 100% defoliation was implemented, hand defoliation produced a greater number of tillers than grasshopper induced defoliation. Similarly, like in the case of herbicide-induced tillering, tolerance may be obtained through the induction of tillering by the herbivory (Kogan and Paxton, 1983).

Alghali (1985), in his studies on Chilo damage and sorghum plant compensation, suggested that damage by the insect induced extra tiller production. In a similar study, induced tillering in rice as a result of damage, has been reported for the stalk-eyed fly (Alghali and Osisanya, 1984).

Factors Associated With Tiller Survival

Blum (1968 and 1969) found more lignification in young leaves and tillers of resistant lines, and noted that lignification was probably a more important factor in tiller survival in shoot fly than silica, since tiller silica level were lower than in main stem. This lignification in tillers as found by Blum, confers resistance on them, so that the plant has 'recovery resistance' (Doggett, 1988). Blum (1968) also found that tillers of all resistant varieties grow faster than those of the susceptible ones.

Recovery Resistance And Crop Losses

Ingram (1958) indicated that in Uganda, despite heavy attack by B. fusca and C. partellus, sorghum yielded well. A similar suspicion was echoed by Harris (1962) in western Africa, and subsequently supported by further studies (Harris, 1964), where the use of insecticides for control gave conflicting results with regard to yield increment. Increase in yield per stand was obtained from bored stands. This was presumably a function of either extra tiller production or selection of potentially higher yielding stems for attack by borers.

There is still notable absence of objective assessments of sorghum yield losses directly attributable to C. partellus (Harris, 1987). Flattery (1982) published the results of field trials over 5 years on grain sorghum in Botswana. He noted that there was often an increase in yield when C. partellus damage resulted in increased tillering and that the inherent tillering ability of one of the cultivars used in the trials (CV 65D) masked any yield reductions that might have resulted from attack by this pest. Some yield decreases were recorded following a high level of C. partellus attack, but were not statistically significant. These results were interpreted by the author as supporting the view expressed by Doggett (1988) that sorghum can produce a good crop and feed a large borer population, but the compensatory growth following borer damage may be reduced during periods of stress.

Alghali (1987) studied the effect of time of C. partellus infestation on yield loss and compensatory ability in sorghum cultivars. The results showed that more tillers were produced by the infested plants, with the plants infested two week after germination producing the most. The varieties differed significantly in their production of secondary tillers, with Serena, LC 119/80-2 and P10/1 producing the most. In general, tillers from infested plants produced fewer panicles and had higher proportions of juvenile panicles. Plants infested two week after germination were the least effective and had higher proportions of juvenile panicles. Varieties did not differ significantly in their proportions of effective tillers and juvenile panicles. Yield components were slightly reduced in the infested plants in all varieties, particularly those infested 2-4 week after germination, except in LC 119/80-3 where there were yield gains. There was direct relationship between yield and deadheart production in Serena and NES 7360.

In studies on the effect of cultivar, time and density of C. partellus infestation on sorghum yield components in Kenya, Alghali (1986) found that damage to plants was greater on young plants with higer levels of infestation. Secondary tiller production was influenced by damage to primary tillers, which was related to the time and amount of infestation. The time of infestation was critical for panicle production; young plants in the vegetative phases were the most affected. The total grain yields were reduced in the infested plants and the extent was dependant on the cultivar, time and level of infestation. plants with more infestation at the young stages of growth showed the most yield reduction, which was caused by reduced numbers and weights of primary tillers and by the secondary tillers produced being less effective.

MATERIALS AND METHODS

SORGHUM GENOTYPES

The present study was started with 228 Sudanese germplasm accessions. Seeds were supplied by the Genetic Resourses Unit (GRU) of ICRISAT, Hyderabad, India. The accessions were selected on the basis of photoperiod insensitivity, maturity cycle, and location within the country.

The 228 accessions were initially screened in the field at ICRISAT Center, under artificial *C. partellus* infestation in order to identify materials with high levels of recovery resistance. Forty eight accessions were retained. Due to considerable infestation by shoot fly, *Atherigona soccata* Rond., which results in deadheart formation, the 48 selected germplasm accessions were further evaluated in the glasshouse under strict shoot fly control. Eight lines with the highest level of tiller survival were retained (Appen. C). These lines were then planted in the field and further evaluated under both rainy (kharif) and post-rainy (rabi) season conditions at ICRISAT Center.

INFESTATION

Natural infestation by *C. partellus* is low and irregular at ICRISAT Center. Consequently, plants were infested artificially in the present study. Insects were reared on artificial diet (Appen. D) at the Cereals Entomology Insect Rearing Laboratory, ICRISAT (Taneja and Leüschner, 1985; and Taneja and Nwanze, 1988). For field and glasshouse infestations, first instar larvae were introduced into the leaf whorl (Plate 2A), by using the modified 'bazooka' applicator developed at the International Maize and Wheat Improvement Center (CIMMYT, Fig. 2 ; Mihm et al., 1978, and Wiseman et al., 1980). Under standard field infestation, at each stroke of the applicator, seven to eight larvae were dispensed into the leaf whorl (Nwanze et al., 1991). Five hundred egg masses containing nearly 15000 black-head stage eggs were kept overnight in a jar with 80 g of gusgus seeds (*Papaver sp*) as a carrier. The following morning, the eggs hatch and the first instar larvae were gently mixed with the carrier (Plate 2B). The mixture was transferred into the plastic bottle attached to the dispenser (Fig. 2). This amount was sufficient to infest about 1000 plants. Different sizes of the "bazooka" applicator were used for main stem and tiller infestation (Plate 3).

Main Stem

Usually, sorghum plants are artificially infested in the field at 15-20 days after emmergence (DAE) (Seshu Reddy and Davies 1979, and Taneja and Leüschner, 1985). For initial screening of germplasm and rainy season evaluation studies of the selected accessions, infestations were carried out 15 DAE. For postrainy season experiment, plants were infested at 25 DAE and large-sized "bazooka" was used. All infestations in the glasshouse were done at 10 DAE by using small-sized "bazooka" (Nwanze et al., 1991 ; Plate 3B) and standard field infestation level. Main

Plate 2A. First instar larvae of C. partellus introduced into the leaf whorl with the "bazooka" applicator.

Plate 2B. Mixture of newly hatched larvae of C. partellus and Carrier (seeds of Papaver sp.)

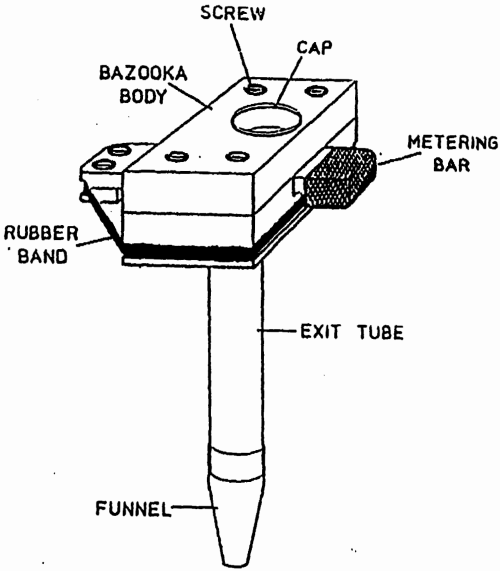
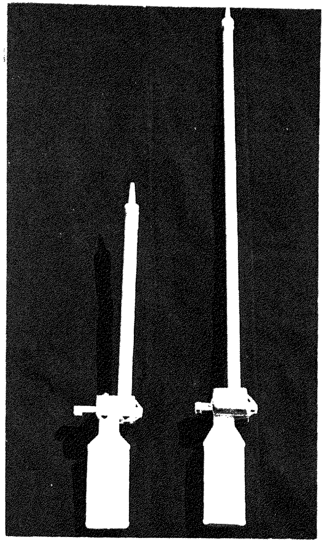
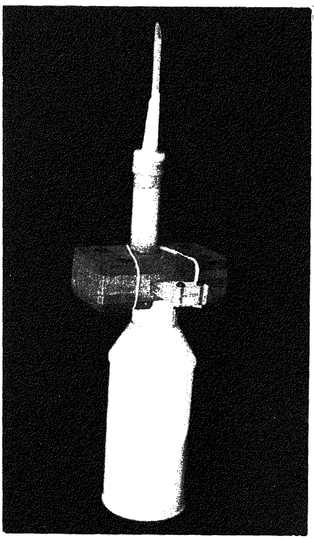


Figure2. The modified 'bazooka' applicator (Mihm et al., 1978) used for infesting with Chilo larvae. Plastic bottle removed to reveal details of the 'bazooka'. (Source: Smith, 1989).



(A)



(B)

Plate 3. Different sizes of "bazooka" applicator used for *C. partellus* artificial infestation of main stem and tillers. (A) Meduim and large, (B) small size.

stems were infested by carefully placing the larvae in the leaf whorls to avoid tiller contamination.

Tillers

Post-rainy season

Tillers in all selected lines were infested according to three age groups: 14, 21, and 28 days after tiller appearance. Ten tillers were randomly selected for each age group. Due to irregular supply of laboratory reared larvae, tillers were infested by fixing the time of infestation, as a reference, and selecting tillers of the three age groups accordingly. As a result, tillers were retagged using tags of three different shapes to indicate the three age groups. By following this method, the whole tiller infestation for all lines was done in three successive days. A medium-sized "bazooka" applicator was used for tiller infestation (plate 3A).

Rainy season

Ten tillers were selected as a sample, to represent each age group. Tiller infestation was carried out for the eight lines and the susceptible check,i.e. CSH 1. For IS 9751, IS 3492, IS 22498, and IS 25041, 14 day-old tillers were infested. While for IS 19624, IS 19652, and CSH 1 two age groups (i.e. 14 and 21 days old tillers) and three age groups (i.e. 14, 21, and 28 days old) of IS 19474 and IS 22806 were infested. The laboratory supply of larvae was adequate in the rainy season and it was possible to use the date of tiller appearance as a reference and selecting tillers for infestation accordingly. A small "bazooka" applicator was used. This method more closely simulates natural field conditions and it was possible to carry out tiller infestation for 27 days.

FIELD STUDIES

Initial Screening of Germplasm

The 228 Sudanese sorghum germplasm lines were machine sown on 27 July, 1990, in single-row plots of 4 m length and 75 cm between rows on a vertisol soil at ICRISAT Center. The susceptible CSH 1 was planted as borders before planting of test entries. All agronomic practices such as land preparation, irrigation, fertilizer application, etc. were carried out as per standard ICRISAT procedures. Thinning to one plant per stand and 10 cm between plants was done at 10 DAE. Stem borer resistant (ICSV 700, IS 2205, IS 214 and IS 1044) and susceptible lines (ICSV 1, ICSV 112, CSH 1 and CSH 5) were sown as checks with the test entries. Two applications of cypermethrin electrodyne spray (22.5 g a.i./h) were applied at five and eight DAE to control shoot fly infestation. The following data were recorded:

(a) Total number of plants per row.

(b) Number of stem borer deadhearts per row, at 15 days after infestation (DAI).

(c) Number of shoot fly deadhearts per row, at 15 DAI.

(d) Recovery rating, at 58 DAE using a 1-9 scale (where 1= excellent, and 9=very poor; ICRISAT, 1991).

Post-rainy (Rabi) Season Evaluation Studies

The eight lines selected from glasshouse studies (Appen. C) were sown on 28 Dec, 1990, on black soil at ICRISAT with supplimental irrigation. This experiment was designed as a split-plot with three replications and three infestation levels (i.e. no infestation, main stem infestation, and main stem with tiller infestation as the main plots and genotypes as the sub-plots). In each replication the main plot size was 18 x 4 m (i.e. 8 genotypes 3 rows of 4m length, 75cm apart) and sub-plot size was 2.25 x 4 m (i.e. 3 rows of 4 m length, 75 cm apart). Thinning to 10 cm between plants was done 12 DAE. All cultural operations were carried out whenever required. Cypermethrin was applied to prevent shoot fly infestation. After artificial stem borer infestation, shoot fly control was achieved by hand removal and destruction of eggs. This process continued until 25 DAI.

All observations were made from a sample of 20 randomly selected plants from the central row. To eliminate any edge-effects 0.5 m on both ends of the central row were avoided. The following observations were recorded:

(a) Tiller appearance

Tillers were tagged at appearance and appropriately dated with a color for each two successive dates to facilitate tiller infestation (Plate 4).

Plate 4. Colored tags used for recording date of tiller appearance.

(b) Rate of tiller growth

Growth of tillers was recorded to the nearest cm from the base to the tip of the longest leaf on five randomly selected plants. Measurements were taken at 4-day intervals from date of tiller appearance and continued for 24 days. The rate of tiller growth was recorded from main stem infestation treatment only.

(c) Main stem height and number of leaves

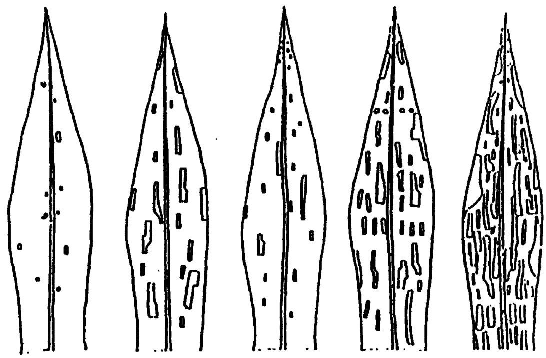
The height of the main stem was recorded at the time of infestation (25 DAE) by measuring the length of the stem from the base to the tip of the longest leaf. The total number of leaves (unexpanded and fully expanded) was also recorded.

(d) Leaf-feeding score

Visual damage rating for leaf-feeding was carried out eight DAI, using the standardized leaf-feeding score system developed at ICRISAT (ICRISAT, 1990; Figure 3). Leaf-feeding scores were recorded from main stem and tillers of the three age groups (14, 21, and 28-day old).

(e) Date of deadheart formation in the main stem

Date of deadheart formation in the main stem was recorded beginning eight DAI. Recording was done for each of the 20 selected plants.



Score	1	3	5	7	9
No. of leaves showing these symptoms	1–2	2–3	3–4	4–5	5–6
Total leaf area damage (mm^2)	150	300–450	600–750	900–1050	1200

Figure 3. Leaf-feeding score system for damage by stem borer C. partellus. (Source: ICRISAT Annual Report, 1989).

(f) Angle of tiller

This is the angle between a tiller and the main stem. It was measured on the early tillers using the bevel protractor (Plate 5). Measurements were taken from five tillers, randomly selected from five plants at 12 DAE.

(g) Height and number of leaves from tillers

Five tillers were selected to represent each age group. Measurements were recorded as for the main stem.

(h) Tiller mortality

Death of tillers due to stem borer, shoot fly, and other mortality factors were recorded. The process continued for 30 DAI. Deadheart formation in the infested tillers of the three age groups was also recorded.

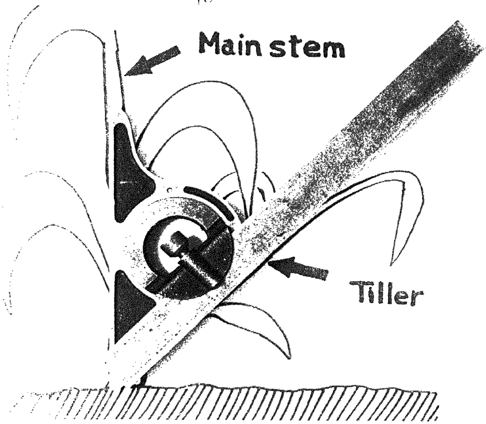
(i) Boot leaf stage

The boot stage (head extended into flag leaf sheath; vanderlip, 1979) was recorded to indicate maturity period for the main stems.

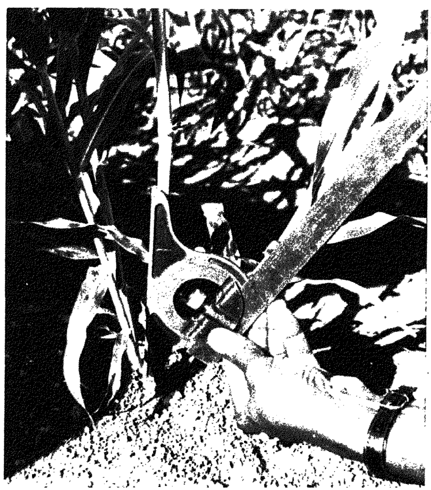
(j) Main stem and tiller productivity

At harvest, harvestable panicles on main stems and tillers were counted and evaluated separately. After harvest, they were air-dried and weighed, then threshed and grain mass was recorded. The number of immature (i.e. non-productive tillers) was also recorded.

Meteorological data on temperature were obtained from the meteorological station on ICRISAT farm (Appen. D).



(A)



(B)

Plate 5. The bevel protractor used for measuring angle of tiller with the main stem. (A) the bevel protractor measuring 45°, (B) Measurement of angle from a plant at the field.

Rainy (kharif) Season Evaluation Studies

The eight selected lines (Appen. C) and two checks (resistant ICSV 700 and susceptible CSH 1) were sown on 17 June, 1991. Seeds were obtained by selfing some heads from the rabi experiment (from noninfested plots). The experimental design procedures and data collected were the same as in the post-rainy season studies.

GLASSHOUSE STUDIES

Screening of the Germplasm

Forty eight Sudanese sorghum germplasm accessions, with resistant and susceptible checks, were sown in pots (10.5" diam) at the rate of five seeds per hole and four holes ten cm apart were made in each pot. Thinning to one plant per hole was done six DAE. Due to unavailability of space for the lines, sowing was done in two sets; the first set of 32 entries and five checks (resistant ICSV 700 and, IS 2205; susceptible ICSV 1 and CSH 1 and the variety Serena) were sown on 4 Oct, 1990. The second set of 16 entries and two checks (IS 2205 and CSH 1) was sown on 19 Oct, 1990. The variety "Serena" (IS 18520) was used because it has a good level of recovery resistance to shoot fly (Doggett *et al.* 1970, and Stark, 1970).

Pots were irrigated every 2 days, and urea was applied as water solution at the rate of 2g dissolved in 100 ml of water per pot at 15 and 25 DAE. One additional dose of 4 g dissolved in 200 ml of water per pot was given 56 DAE. Infestation with *C. partellus* first instar larvae was done at 10 DAE and protection against shoot fly was achieved by covering plants with cages at 18.00 hr and removing them next day at 08.00 hr. Shoot fly eggs were hand destroyed. The following observations were recorded:

(a) Tiller appearance by tagging and dating.

(b) Leaf-feeding score at eight DAI.

(c) Date of deadheart formation in the main stem.

(d) Tiller mortality.

(e) Recovery rating at 44 DAE, evaluated on 1-9 scale (where 1=excellent, 3=very good, 5=good, 7=poor, and 9=very poor recovery).

(f) Number of recovered plants (main stem died but plants recovered).

Pot Experiment on Insect-Induced Tillering

Genotypes

The varieties CSH 1 and IS 19624 were selected in this study to represent genotypes that produce tillers more or less, as a response to damage to growing point by insects or any other means.

Lay-out and treatments

These studies were laid out as paired plots, insect infested and mechanically damaged plants, with healthy plants as check. each treatment was replicated six times.

Pot preparation and cultural practices

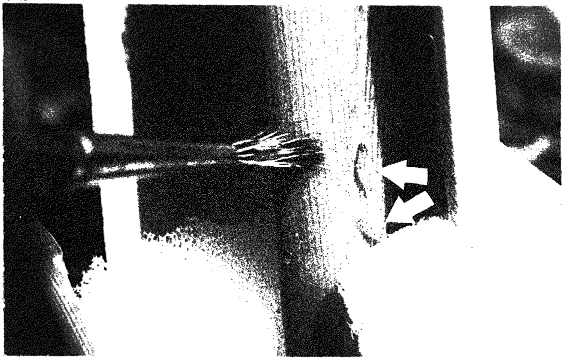
Pots were watered before sowing and sowing was done on 31 May, 1991, in 8" diam. pots and two plants, 15 cm apart were raised per pot. Each pot represented one replication. Irrigation was done at two days interval after sowing. Urea was applied in water solution at the rate of 1 g dissolved in 100 ml of water per pot at 6 and 11 DAE. Two additional doses of 2 g dissolved in 200 ml of water per pot were given 23 and 37 DAE.

Infestation and stem cage technique

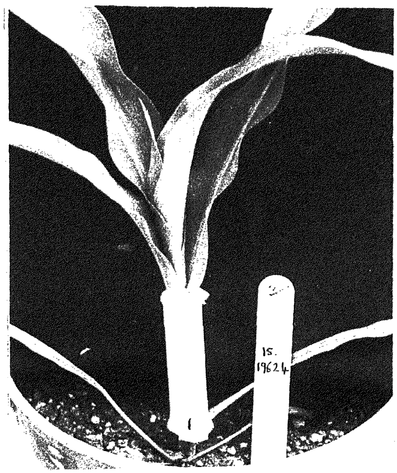
In order to restrict larvae to the main stem and prevent migration to tillers, the stem cage technique was used (ICRISAT, 1988). The cage was made from plastic material, 7 cm in length and 5.5 cm in diam. Seven days old larvae were released on CSH 1 at 18 DAE in the cage fitted arround the stem (Plate 6) and eight days old larvae on IS 19624 at 19 DAE. Time of releasing the larvae in the cage was determined experimentally by recording the time in DAI at which the larvae start penetrating at base of the stem. Two larvae were released in each cage.

Mechnical induction of tillers

To induce tillering in the two genotypes, the destruction of the growing point was simulated by opening a small triangular incision with a blade 2 cm above the root crown. Position of the



(A)



(B)

Plate 6. The stem cage used for restricting the larvae to the main stem. (A) Larvae released by a brush in the cage, (B) cage closed.

incision was determined by conducting a trial in which the growing point was destructed mechanically 1,2, and 3 cm above the root crown. Through the open incision, a needle was inserted in a downward direction and carefully rotated (Plate 7). This was done on seedlings of CSH1 at 18 DAE and IS 19624 at 19 DAE. Data recorded were :

(a) tiller appearance
(b) date of deadheart appearance

STATISTICAL ANALYSIS AND CALCULATIONS

The data from all studies were subjected to various statistical analyses using the GENSTAT statistical package on the mainframe VAX computer. The statistical design used for the glasshouse screening studies was a completely randomized design (CRD). In these studies some of the infested plants were completely killed (Plate 9B), but others survived through tillers. The infested plants which gave rise to surviving tillers were termed "recovered plants". The percent recovered plants was calculated as number of recovered plants to the total plants. In calculating number of tillers appearing before and after deadheart formation, only deadheart plants were considered. Percent tiller survival was calculated as the number of surviving tillers to the total number of tillers. The percent tiller survival provided an index of "recovery resistance".

For field evaluation studies, data on various characters were analysed using both split-plot and randomized complete block (RCB) design. The RCB design was used for analyzing the data which were recorded from one treatment (height of plant, number of leaves, leaf-feeding damage, deadheart formation, data of deadheart appearance, tiller growth, angle of tiller, and boot

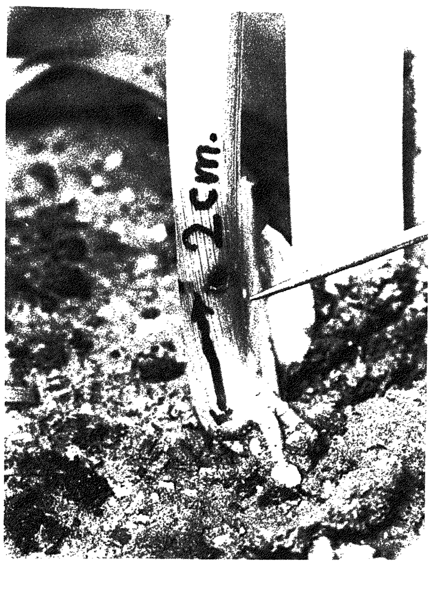


Plate 7. The mechanical destruction of the growing point by a needle inserted through an open incision made at the stem base 2 cm above the root crown.

stage). Data on pattern of tiller appearance under infestation were also analyzed by using RCB design. Data related to fate of tillers and yield in the infested and non-infested treatments were analyzed by using split-plot design. The interaction between the genotype and infestation was not of prime importance in these studies. For fate of tillers under infestation percentages of the different constituents were calculated as the number of tillers in each group to the total number of tillers. Percent contribution of tillers in total grain yield was calculated as tillers grain weight to the total grain weight (main stem and tillers). Percent reduction in grain yield in the infested treatments were calculated as illustrated in appen. O. Paired t-test was used for comparing deadheart formation in main stem and main stem with tiller infestation treatment. The comparison between damage due to leaf-feeding and deadheart formation in the three age groups of tillers (14,21, and 28- day old) was done also through t-test of significance (Appen. H). t-test of significance was also used to compare the different parameters considered in glasshouse studies on insect-induced tillering (Appen. Y).

Fisher's least significant difference (FLSD) was adopted in these studies in mean separation. However, the FLSD may be preferred due to its familiarity and its simplicity of application (Carmer and Swanson, 1971).

Correlation studies were conducted for the parameters studied in the glasshouse screening and field evaluation studies (Table 2, and Appens. G and P).

Canonical variate analysis (Singh and Chaudhary, 1977) was used in glasshouse screening to cluster the 37 sorghum lines into homogenous groups based on percent plants recovered, percent tiller survival, and recovery score (Fig.6). The same statistical technique was followed by Omori et al. (1988) in studies of a number of characters related to shoot fly resistance in sorghum. The efficiency of clustering was tested through ANOVA procedure (Appen. F).

Combined statistical analyses were done for the data related to tiller production and percent contribution of tillers in total grain yield collected from the two seasons (Appens. W and X).

The data related to pattern of tiller appearance under infestation were transformed following square root transformation; angular transformations were done whenever necessary.

RESULTS

INITIAL FIELD SCREENING OF THE ACCESSIONS

Results of the initial screening of germplasm accessions are presented in appen. E. The overall average percent deadhearts was 86.2% of which 47.4% was caused by C. partellus and 39.4% by the shoot fly. Deadhearts caused by the shoot fly started to appear 9 days after artificial Chilo infestation and since shoot fly population was also building up, this resulted in difficulties in controlling this pest by hand-removal of eggs.

Recovery from damage (based on visual rating scale of 1-9), followed a normal distribution with most genotypes (78%) showing only moderate levels (5-7) of recovery resistance (Fig. 4). However, no genotype fell under category 1 (highest recovery) or 9 (lowest recovery).

Based on the results of the initial screening, 41 lines with recovery scores 2-4 and 7 lines with score 5 were selected for glasshouse screening. Five other lines were added as control.

GLASSHOUSE SCREENING OF SELECTED ACCESSIONS

Results of the first planting showed highly significant differences ($P < 0.001$) between the 32 lines in all parameters (Table 1). Excluding checks, the highest leaf-feeding score (5.8) was recorded in IS 939, IS 9983, and IS 7051 and was at par with the susceptible variety CSH 1. The lowest (1.8), was recorded in IS 22864 and IS 22555, and was similar to that recorded for the resistant check ICSV 700. The correlation

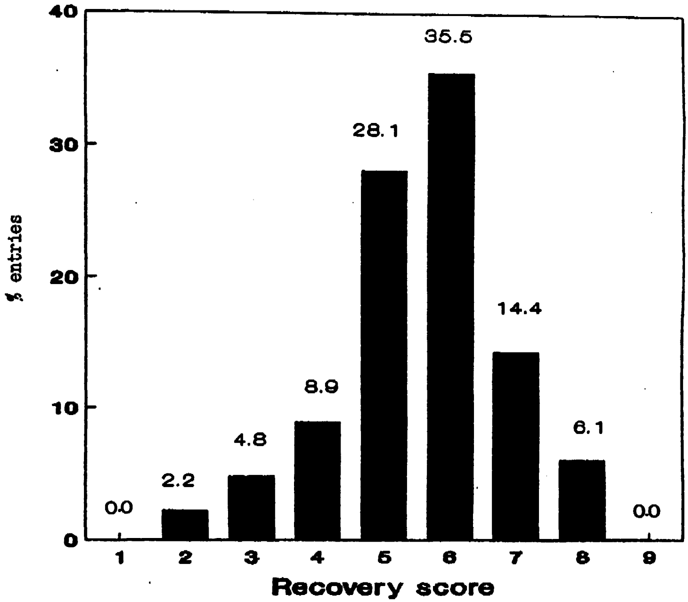


Figure 4. Distribution of percent entries with the recovery scores: Initial field screening of the germplasm accessions.

Table 1. Results of glasshouse screening of the selected germplasm accessions: First planting.

IS No.	leaf-feeding score	Dead-hearts (%)	(%) recovered plants	Number of basal tillers/ plant	Number of[1] basal tillers appearing before DH/ plant	Number of[1] basal tillers appearing after DH/ plant	Number of surviving tillers/ plant	Tiller survival (%)	Recovery Score
19474	3.0	95.0 (84.0)[2]	70.0 (60.0)[2]	4.2	0.7	3.7	2.3	54.4 (47.6)[2]	2.2
19652	4.6	95.0 (84.0)	90.0 (78.0)	4.3	0.6	3.8	2.3	53.8 (47.2)	1.0
9751	3.8	80.0 (66.0)	93.3 (83.0)	5.7	1.9	3.2	2.7	46.7 (43.1)	2.2
19624	4.2	95.0 (84.0)	80.0 (72.0)	3.9	0.0	4.0	1.7	44.5 (41.8)	3.8
22498	2.6	85.0 (75.0)	70.0 (60.0)	4.5	1.4	3.0	2.0	44.5 (41.8)	2.6
22808	3.8	100.0 (90.0)	70.0 (60.0)	3.5	1.4	2.4	1.6	43.3 (41.1)	2.6
3492	3.8	75.0 (66.0)	81.7 (73.0)	5.4	2.1	3.7	2.4	42.7 (40.7)	1.4
19653	2.2	100.0 (90.0)	95.0 (84.0)	6.1	0.6	5.5	2.5	39.7 (39.0)	2.2
25041	3.8	95.0 (84.0)	85.0 (75.0)	6.1	2.3	3.8	2.5	39.1 (38.4)	2.6
2314	4.2	100.0 (90.0)	65.0 (57.0)	2.2	0.0	2.2	0.3	35.6 (36.4)	5.4
2309	4.2	75.0 (63.0)	70.0 (59.0)	3.0	0.1	3.3	1.2	34.2 (35.5)	4.8
22511	2.2	95.0 (84.0)	85.0 (72.0)	2.8	0.0	2.6	0.9	33.1 (35.1)	3.8
19228	4.2	100.0 (90.0)	80.0 (69.0)	4.9	0.1	4.7	1.5	31.2 (33.9)	2.6
22864	1.8	100.0 (90.0)	65.0 (60.0)	4.4	1.8	2.6	1.3	30.8 (33.0)	3.4
22523	3.4	85.0 (75.0)	65.0 (60.0)	4.4	1.3	2.2	1.3	30.6 (33.1)	5.0
2305	2.6	85.0 (75.0)	38.3 (38.0)	3.2	0.2	2.9	1.0	30.0 (32.6)	5.8
9761	2.6	80.0 (69.0)	83.3 (74.0)	5.3	1.4	3.6	1.5	29.5 (32.9)	3.4
3585	2.2	100.0 (90.0)	55.0 (45.0)	2.3	0.2	2.8	0.9	29.3 (29.7)	7.0
19203	3.0	95.0 (84.0)	83.3 (56.0)	2.5	0.2	2.6	0.9	28.8 (31.7)	6.2
19098	5.0	100.0 (90.0)	35.0 (33.0)	2.1	0.1	2.0	0.6	27.2 (28.4)	8.6
9837	4.2	90.0 (81.0)	45.0 (42.0)	3.4	0.6	2.8	0.9	27.0 (30.8)	8.2
939	5.8	75.0 (63.0)	55.0 (48.0)	5.7	0.3	5.7	1.6	26.7 (30.8)	5.4
6974	4.6	100.0 (90.0)	43.0 (37.5)	3.2	0.3	2.9	1.0	25.9 (26.8)	7.5
9749	4.6	90.0 (78.0)	46.7 (38.9)	1.9	0.5	1.6	0.5	25.3 (28.4)	7.8
21760	2.2	95.0 (84.0)	48.3 (41.0)	3.0	0.2	2.9	0.7	22.3 (24.9)	7.0
22360	3.0	80.0 (69.0)	53.3 (44.0)	3.8	0.0	3.5	0.7	20.3 (26.6)	6.6
9687	5.8	95.0 (84.0)	41.7 (43.0)	4.4	2.8	1.8	0.8	18.5 (24.6)	6.2
9983	2.2	85.0 (75.0)	29.3 (26.0)	3.0	0.8	2.5	0.6	18.4 (22.7)	7.4
9762	2.6	90.0 (81.0)	50.0 (45.0)	4.0	1.5	2.9	0.8	18.2 (22.2)	6.8
20515	3.8	100.0 (90.0)	40.0 (33.0)	2.9	0.3	2.6	0.5	13.5 (18.4)	7.0
22555	1.8	100.0 (90.0)	30.0 (30.0)	3.4	0.6	2.8	0.4	11.4 (17.9)	7.4
7051	5.8	100.0 (90.0)	10.0 (12.0)	2.7	1.7	1.0	0.2	4.4 (7.6)	8.6
Serena	3.8	95.0 (84.0)	75.0 (66.0)	4.4	0.7	3.8	1.8	41.3 (40.0)	3.4
ICSV 700	1.8	55.0 (48.0)	83.3 (74.0)	2.1	0.4	2.5	0.8	38.6 (37.2)	7.0
IS 2205	1.4	65.0 (54.0)	73.0 (65.8)	3.2	0.1	3.6	1.0	30.5 (32.7)	6.6
ICSV 1	3.4	95.0 (84.0)	95.0 (84.0)	3.8	0.5	3.4	1.1	29.6 (32.8)	5.8
CSH 1	5.8	90.0 (78.0)	60.0 (54.0)	3.0	0.9	3.1	0.7	22.8 (28.1)	5.8
Mean	3.5	90.2 (79.6)	62.7 (55.5)	3.7	0.7	3.1	1.2	30.9 (32.3)	5.1
SE ±	1.4***	14.29 (14.02)**	27.7 (24.05)***	0.93***	0.52***	1.10***	0.57***	11.88 (9.57)***	1.56***
CV (%)	32.4	15.0 (17.6)	44.2 (43.3)	24.8	71.8	35.1	46.2	37.9 (29.7)	31.1
$LSD_{0.05}$	3.16	39.60 (39.35)	76.77 (66.65)	2.58	1.44	3.04	1.58	32.4 (26.52)	4.38

1. Calculated from plants showing deadheart (DH)
2. Angular transformations. ***=Significant at 0.1%, ** =Significant at 1% level.

coefficients matrix of the parameters studied is given in table 2 . There was no correlation between leaf-feeding score and number of basal tillers produced per plant (r=0.01). Mean deadheart formation was 90.1% (range 75-100% ; Table 1). The correlation coefficient between percent deadheart and number of tillers produced per plant was 0.01. Plant recovery (ratio of plants recovering after deadheart over total number of plants recorded) varied considerably between genotypes (10.0 to 95.0%).

The correlation coefficients between percent recovered plants, and recovery scores, number of surviving tillers per plant and percent tiller survival were -0.72, 0.65, and 0.64, respectively. The highest number of basal tillers produced per plant (6.1; Table 1) was recorded in the lines IS 19653 and IS 25041. The line IS 9749 showed the lowest number of basal tillers produced per plant (1.9; Table 1). Several lines produced more tillers per plant than the variety "Serena". The correlation coefficients between the number of tillers produced per plant, and recovery score, number of tillers surviving per plant, and percent tiller survival were -0.62, 0.79, and 0.38, respectively (Table 2). Tiller production occurred before deadheart formation in most lines. This observation was most pronounced in IS 25041 and IS 9687 with 2.5 and 2.6 tillers per plant, respectively. Line IS 19624, IS 2314, IS 22511, IS 22360, and susceptible CSH 1 produced tillers only after deadheart formation.

The highest tiller survival (2.7/plant) was recorded in IS 9751, whereas the lowest was recorded in IS 7051 (0.2/plant).

Table 2. Correlation coefficient matrix of the parameters studied in the glasshouse: First planting[1].

	Recovery score	Tiller survival (%)	Number of surviving tillers/plant	Number of basal tillers /plant	% Recovered plants	Dead-heart %	Leaf-feeding score
leaf-feeding score	–	–	–	0.01^{NS}	–	–	
Deadheart (%)	–	–	–	0.01^{NS}	–		
% Recovered plants	-0.72^{**}	0.64^{**}	0.65^{**}	–			
Number of basal tillers/plant	-0.62^{**}	0.38^{**}	0.79^{**}				
Numberof surviving tillers/ plant	-0.75^{**}	0.82^{**}					
Tiller survival (%)	-0.64^{**}						
Recovery score							

1. r tested at 181 d.f.
** =Significant at 1% level, NS=not significant.

A strong correlation coefficient was observed between number of surviving tillers per plant and the total number of tillers produced per plant (r=0.79). Also, a correlation coefficient of -0.75 was recorded between recovery score and number of tillers survived per plant (Table 2).

The results showed tiller mortality due to attack by Chilo larvae in the form of deadheart and tiller breakage particularly in juvenile ones (Plate 8A). Natural tiller death was also observed (Plate 8B). The highest percent tiller survival (54.4%) was recorded in IS 19474 and the lowest was recorded in IS 7051 (4.4%). The correlation coefficient between the percent tiller survival and number of tiller suviving per plant was 0.82. The relaionship between percent tiller survival and recovery score is illustrated in fig. 5 (r=-0.64). The two lines IS 19652 and IS 3492 had the highest recovery scores: 1.0 and 1.4, respectively (plate 9A). The line IS 7051 received the lowest recovery score (8.6; plate 9B).

The result of canonical variate analysis is given in fig. 6 where the 37 lines were distributed on the basis of the three characters, percent plant recovered, percent tiller survival, and recovery score. The result of ANOVA between and within clusters regarding the three parameters showed that there are highly significant differences between clusters and no significant differences exist between the lines within the cluster (Appen. F).

For the second planting there were highly significant differences (P<0.001) between entries in leaf-feeding score and deadheart (Table 3). The highest percent deadheart

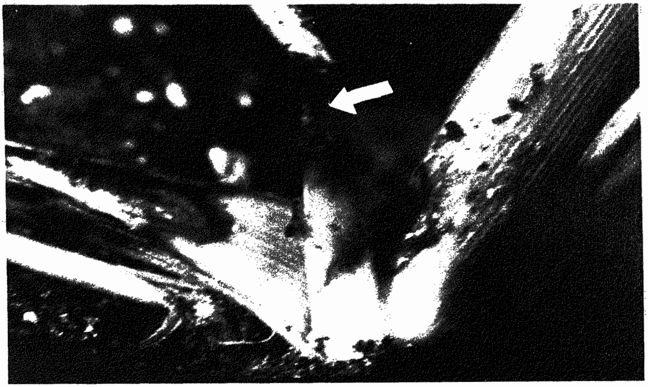


Plate 8 A. Damage of C.partellus to juvenile tillers

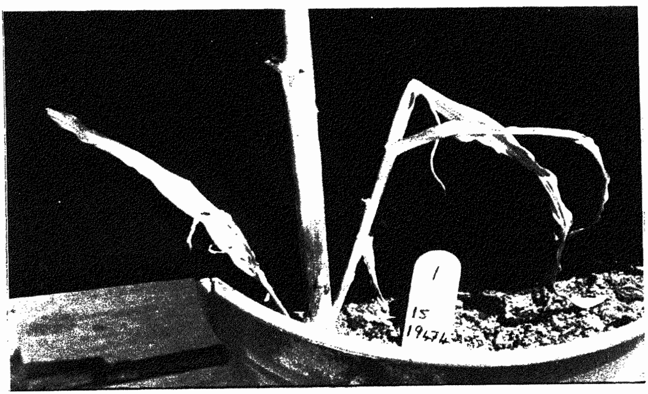


Plate 8 B. Natural death of tillers.

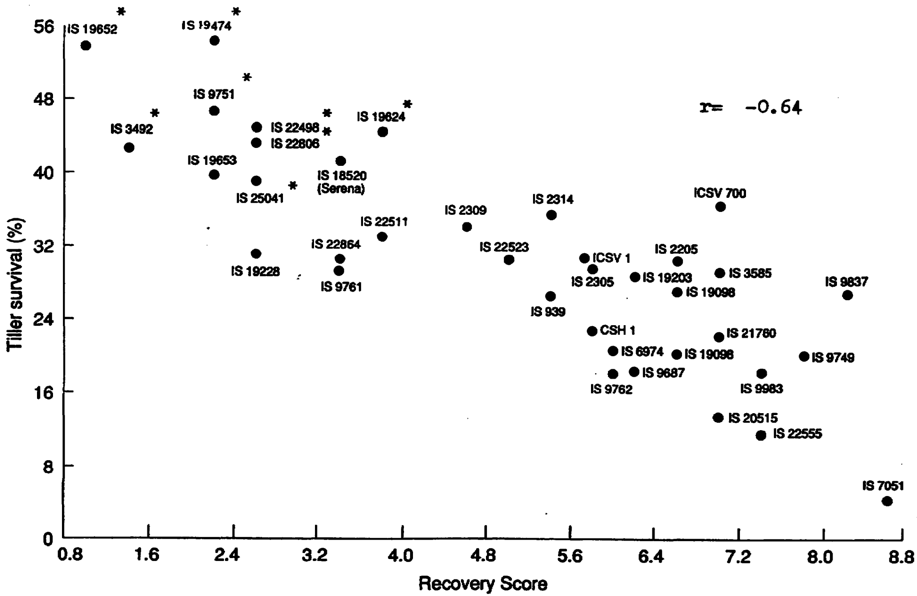


Figure 5. Relationship between percent tiller survival in the 37 lines and recovery scores.
* Selected lines
r= Correlation coefficient

Plate 9A. The five recovery classes with the line IS 3492 showing excellent recovery.

Plate 9B. The line IS7051 with very poor recovery.

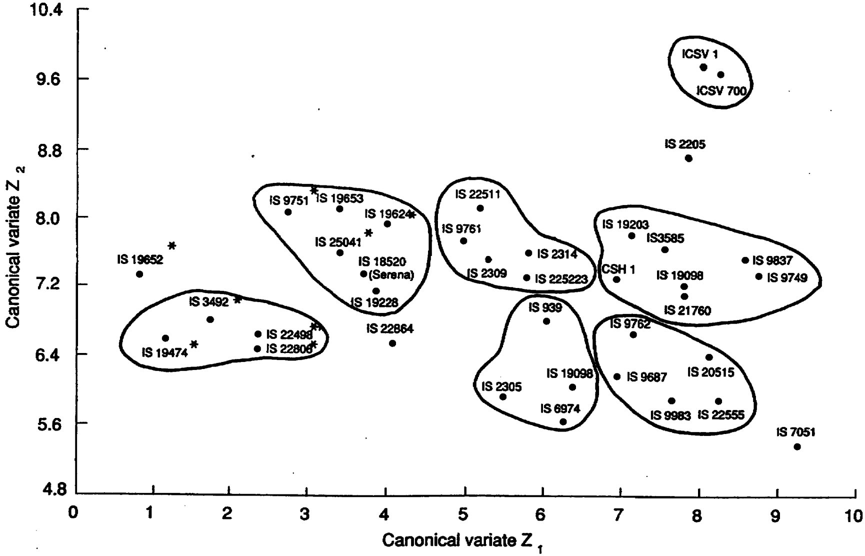


Figure 6. Cluster analysis of 37 sorghum lines for stem borer recovery resistance.

* Selected lines.

Table 3. Results of glasshouse screening of the selected germplasm accessions: Second planting.

IS No.	Leaf-feeding score	Dead-hearts (%)	(%) recovered plants	Number of basal tillers/plant	Recovery score
22407	7.0	85.0 (72.0)[1]	100.0 (90.0)[1]	11.0	4.6
9829	4.2	35.0 (33.0)	90.0 (81.0)	10.1	2.5
9653	4.2	75.0 (66.0)	100.0 (90.0)	8.8	3.8
2303	5.0	45.0 (42.0)	90.0 (81.0)	8.7	3.8
9838	4.2	85.0 (72.0)	100.0 (90.0)	8.6	5.4
9649	6.2	60.0 (51.0)	100.0 (90.0)	8.3	4.6
22563	4.2	90.0 (78.0)	100.0 (90.0)	7.8	1.4
22404	5.8	40.0 (36.0)	95.0 (84.0)	7.6	4.3
3605	3.4	90.0 (78.0)	100.0 (90.0)	7.5	3.0
9884	3.4	30.0 (33.0)	100.0 (90.0)	7.1	5.8
22361	5.0	85.0 (78.0)	100.0 (90.0)	7.0	5.8
20500	6.2	80.0 (69.0)	93.3 (83.0)	7.0	1.8
19598	5.0	60.0 (51.0)	90.0 (81.0)	7.0	3.4
9284	5.0	70.0 (60.0)	100.0 (81.0)	6.0	4.6
19304	4.6	90.0 (78.0)	68.3 (59.0)	4.8	6.2
940	5.8	20.0 (24.0)	100.0 (90.0)	2.8	5.5
CSH 1	5.8	75.0 (66.0)	100.0 (90.0)	7.2	4.6
IS 2205	3.4	60.0 (51.0)	100.0 (90.0)	4.1	5.4
Mean	4.9	65.3 (57.7)	95.4 (85.0)	7.2	4.6
SE ±	1.155***	20.24 (18.44)***	13.10 (11.79)**	1.162***	1.132***
CV (%)	23.5	31.0 (32.0)	13.7 (13.8)	16.0	26.6
$LSD_{0.05}$	3.21	56.09(51.11)	36.31(32.68)	3.21	3.13

(90%) was recorded in IS 22563, IS 3605, and IS 19304. Line IS 940, IS 9884, IS 9829, and IS 2303, showed the lowest percent deadheart (20, 30, 35, and 45%, respectively) compared to susceptible CSH 1, and resistant IS 2205 which recorded 75% and 60% deadheart, respectively. The two lines, IS 9649 and IS 19598, showed deadheart formation similar to IS 2205. Ten lines showed complete recovery (100%) from damage, while five lines showed 90 to 95% recovery. IS 19304 had the lowest recovery (68.3%). The overall average number of tillers produced per plant was 7.2 and the maximum number (11.0) was recorded in IS 22407. Line IS 940 had the lowest number (2.8). The recovery scores showed highly significant differences between entries. Line IS 22563 had the highest recovery score (1.4), while IS 19304 had the lowest (6.2).

POST-RAINY SEASON STUDIES

Main Stem

Significant differences were observed between the lines in stem height measured at infestation (Table 4). The line IS 19624 was the tallest (31.4 cm) while line IS 22498 (23.4 cm) was the shortest. No significant differences were observed in total and fully expanded number of leaves. For leaf-feeding scores, the results, showed significant differences between the lines. Line IS 19652 showed the highest leaf damage (7.0) and IS 25041 registered the lowest damage (3.7; Table 4)

Highly significant differences were recorded between the lines in angle of tiller. The largest angle was recorded in IS 9751 (74.5) and the smallest (21.8) for IS 19474

Table 4. Height of main stem and number of leaves at infestation, leaf feeding score, angle of tiller, deadheart formation and boot leaf stage: Postrainy season.

Sorghum line	Height 25 DAE (cm)	No. of leaves (25 DAE)[1]		Leaf-feeding score	Angle of tiller (degree)	Date of deadheart appearance (DAE)	Deadheart (%)		Boot leaf stage (DAE)
		Total	Fully expanded				T2[2]	T3[3]	
IS 3492	26.3	7	5	5.7	49.0	33.9	70.0(56.8)[4]	75.0(60.1)[4]	39.4
IS 9751	25.8	7	5	5.7	74.5	33.7	75.0(60.1)	73.3(59.0)	39.7
IS 19474	28.8	6	5	5.0	21.8	37.6	63.3(52.7)	68.3(55.9)	61.7
IS 19624	31.9	7	6	5.7	25.9	37.5	61.7(51.8)	63.3(52.8)	47.0
IS 19652	31.4	8	6	7.0	29.3	36.7	66.7(54.8)	66.7(54.9)	43.2
IS 22498	23.4	7	5	4.3	24.0	36.7	50.0(45.0)	58.3(49.9)	40.2
IS 22806	27.2	6	5	5.7	22.1	37.7	65.0(53.8)	60.0(50.8)	63.4
IS 25041	29.6	8	6	3.7	33.0	38.7	46.7(43.1)	50.0(45.0)	58.5
Mean	28.1	7	5	5.3	31.6	36.6	62.3(52.3)	64.4(53.6)	49.1
SE(±)	1.47*	0.77NS	0.58NS	0.68*	2.71**	1.03*	3.6(2.1)**	4.1(2.5)*	2.3**
CV(%)	9.1	18.5	18.6	22.2	14.9	4.9	10.0(7.0)	11.0(8.1)	8.1
$LSD_{0.05}$	4.5			2.1	8.2	3.1	10.9(6.4)	14.4(7.6)	7.0

1 · DAE = Days after emergence, 2 · T2 = Main stem infestation, and 3 · T3 = Main stem with tiller infestation,
4 · Angular transformation.
= **Significant at 1% , *=Significant at 5% level, and NS=not significant .

(Table 4). The correlation coefficient matrix of some parameters studied is presented in appen. G.

Significant differences were recorded in the date of deadheart appearance in DAE between the lines. In IS 3492 and IS 9751 deadhearts appeared relatively earlier than in the other lines (33.9 and 33.7 DAE), while in IS 25041 there was a delay in deadheart appearance (38.7 DAE). The results showed significant differences in percent deadheart (Fig. 7). The highest deadheart percent were recorded in IS 3492 and IS 9751, whereas the lowest percent occurred in IS 25041 and IS 22498. The other lines showed moderate levels of deadheart formation. No significant differences were recorded between deatheart formation in treatments 1 and 2 (Appen. H). There was no significant correlation between deadheart formation and stem height (25 DAE). However, there was a significant correlation between deadheart formation and angle of tiller (r=0.42; Appen. G).

Regarding the appearance of boot leaf stage in DAE, highly significant differences were recorded between the lines. Boot stage appeared early in IS 3492 and IS 9751 (39.4 and 39.7 DAE), while IS 22806 the latest (63.4 DAE).

Total Number of Basal Tillers

Results are presented in figs. 8 and 9; and appen. I. Highly significant differences were recorded in total number of basal tillers between treatments and genotypes. Tiller production in the infested treatments of the genotypes showed significant differences from the control treatment. Line IS 3492 which produces highest number of tillers in the

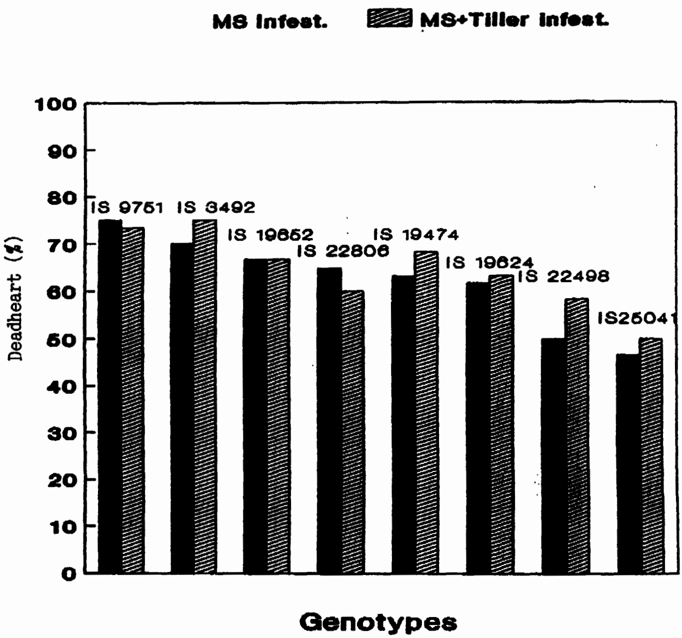


Figure 7. Deadheart formation in the main stem: Post-rainy season.

MS = Main stem

Infest. = Infestation

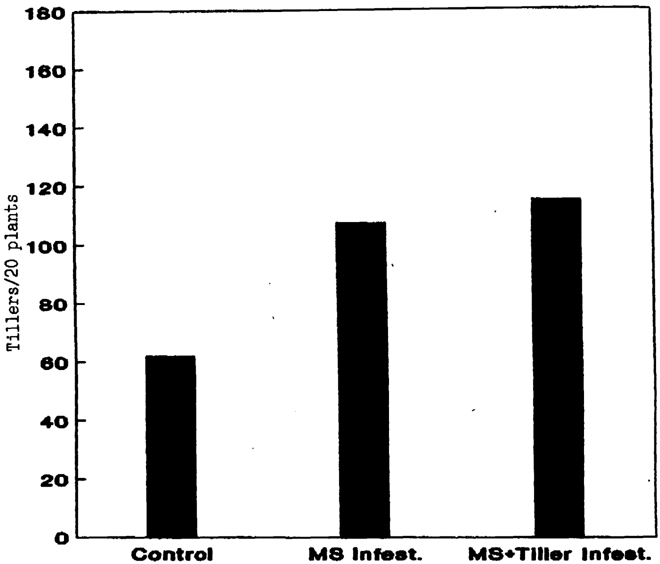


Figure 8. Overall tiller production: Post-rainy season.
MS = Main stem
Infest. = Infestation

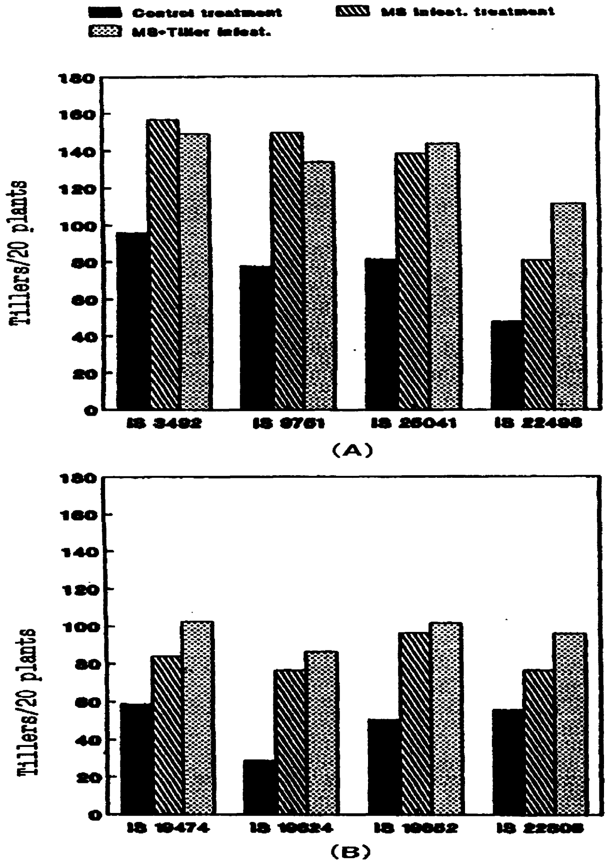


Figure 9. Tiller production in the individual lines: Post-rainy season.

MS = Main stem

Infest. = Infestation

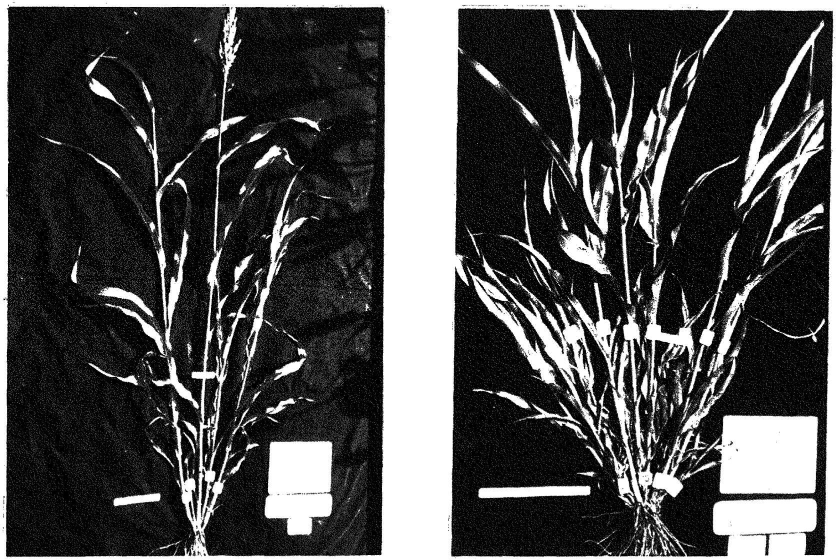
control treatment (95.7) produced 155.7 tillers in treatment 2 (Plate 10). Line IS 19624 produced 28.7 (the lowest) and 76.3 tillers in the control and treatment 2, respectively (Plate 11). In this line also some plants did not produce any tillers in the control treatment (Plate 11A). Plate 12 shows tiller production in IS 19652. Also significant interactions between genotypes and treatments were recorded. The correlation coefficient between total number of tillers (control treatment) and angle of tiller was 0.62 (Appen. G)

Pattern of Tiller Appearance Under Infestation.

Tiller appearance occurred before infestation in all lin (Appen. J; Figs. 10 and 11). The earliest appearance of tillers occurred in IS 3492 and IS 25041, at 16-17 DAE, while in IS 19474, IS 19624, and IS 19652 it occurred late at 22-23 DAE. Generally, the pattern of tiller appearance with time in all lines showed two peaks; one after infestation and the other after deadheart formation. A slight depression between the two peaks was also observed.

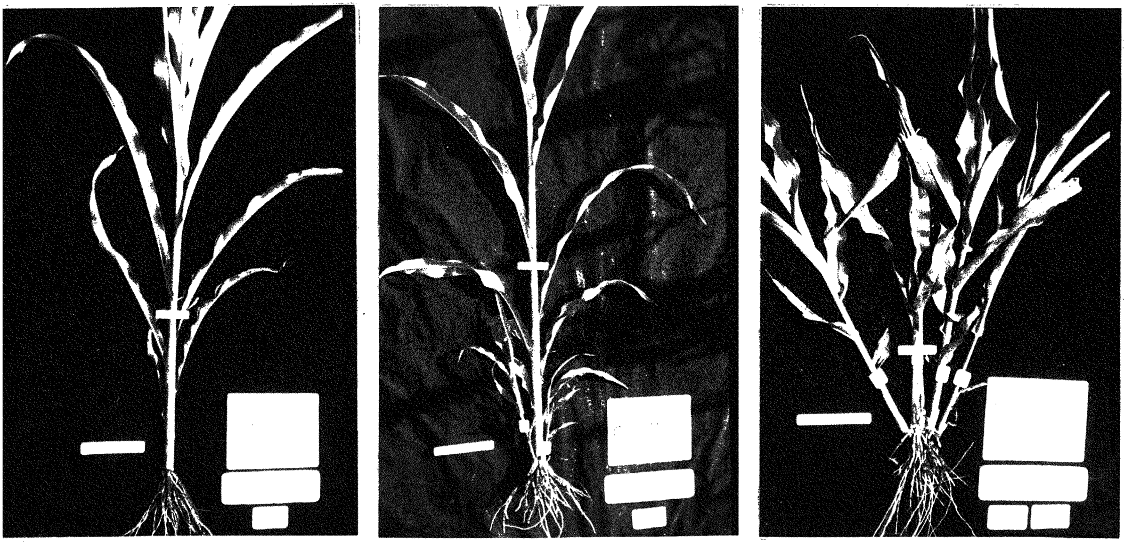
Tiller Height, Number of Leaves, Leaf-feeding Score, And Deadheart Formation

Significant differences in tiller height at 14 and 28-day old were observed, but at 21-day old the differences were not significant (Table 5). No significant differences were observed in number of leaves (total and fully expanded) at the three age With regard to leaf-feeding scores, significant differences were recorded between lines only for the 14-day old tillers. The results of comparison between the three age groups in leaf damage is presented in appen. H. The results also showed



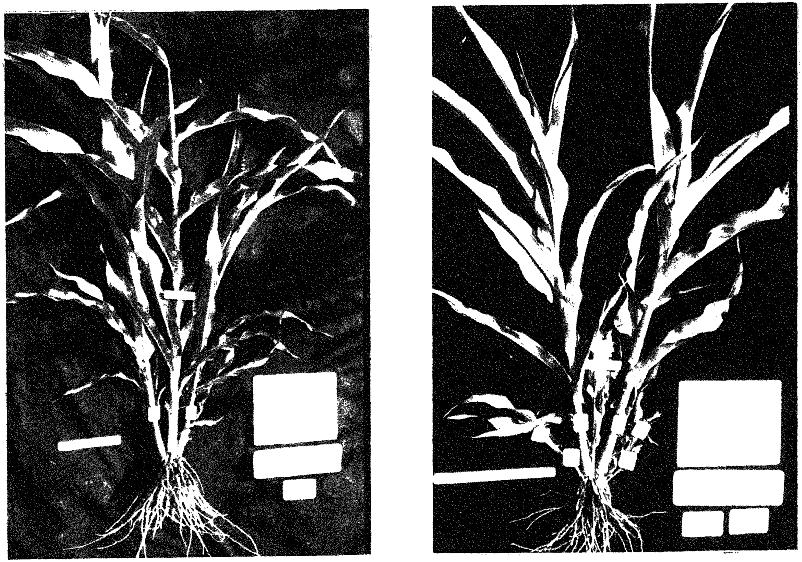
(A) (B)

Plate 10. Tiller production in IS 3492: Post-rainy season.
(A) Control, (B) Infested treatment.



(A) (B) (C)

Plate 11. Tiller production in IS 19624: Post-rainy season.
(A) Control without tillers (B) Control with weak tillers
(C) Infested treatment.



(A) (B)

Plate 12. Tiller Production in IS 19652: Post-rainy season.
(A) Control, (B) Infested treatment.

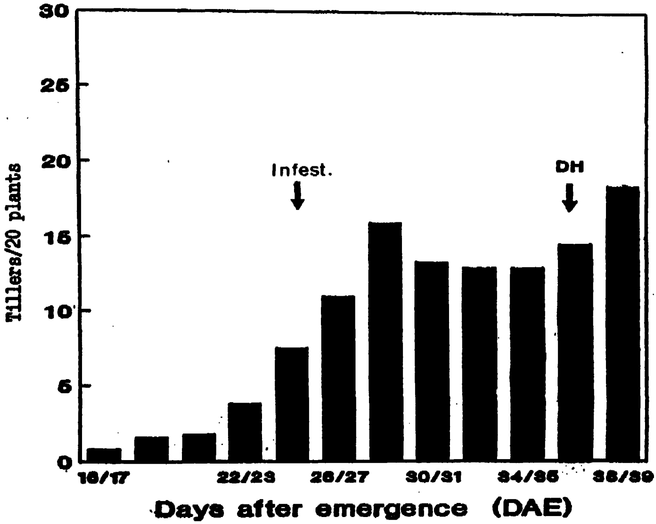


Figure 10. Pattern of tiller appearance under *C. partellus* infestation: Post-rainy season.

DH = Deadheart

Infest. = Infestation

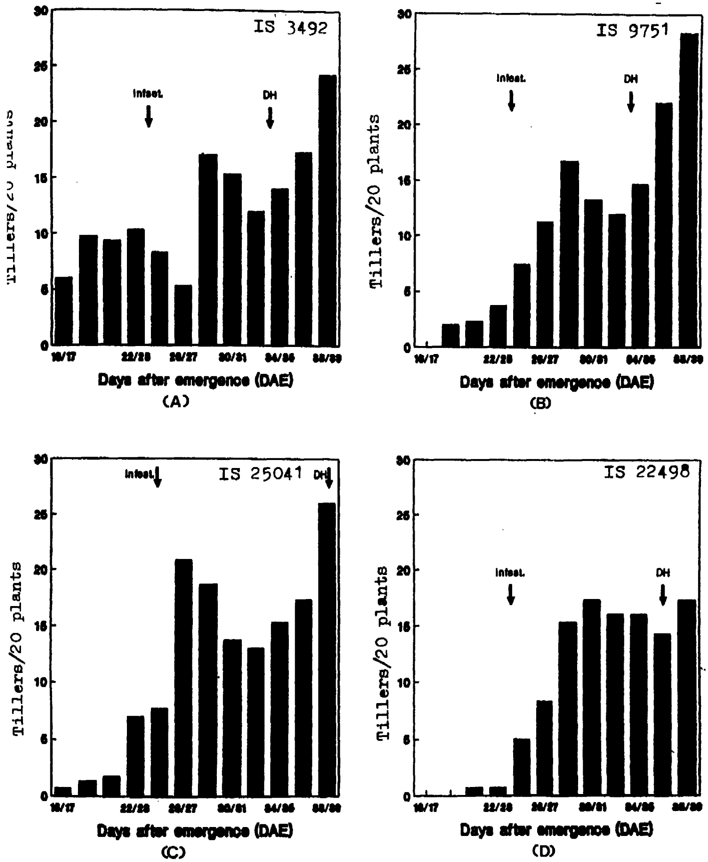


Figure 11. Pattern of tiller appearance under C.partellus infestation in the individual lines: Post-rainy season.

DH=Deadheart

Infest.= Infestation

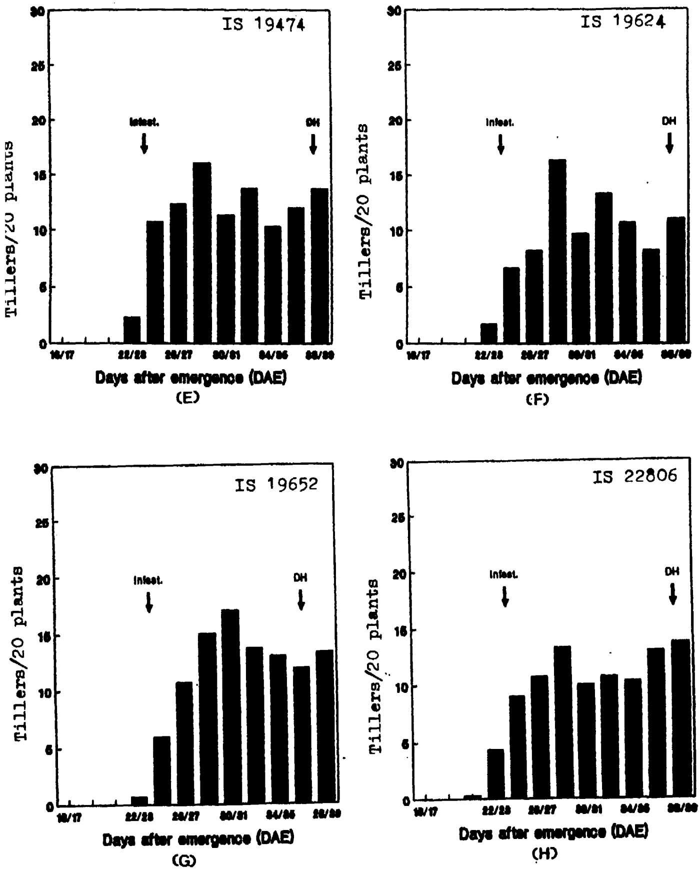


Figure 11 continued.

Table5. Height and number of leaves in 14,21,28-day old tillers with leaf-feeding scores and percent deadheart: Post-rainy season.

Sorghu line	Height (cm) 14	Height (cm) 21	Height (cm) 28	Number of leaves Total 14	Total 21	Total 28	Fully expanded 14	Fully expanded 21	Fully expanded 28	Leaf-feeding Score 14	Leaf-feeding Score 21	Leaf-feeding Score 28	Deadheart (%) 14	Deadheart (%) 21	Deadheart (%) 28
IS 3492	26.9	38.1	56.1	6.4	7.1	8.9	4.5	4.9	6.8	5.0	4.3	3.7	46.7(43.0)[1]	13.3(17.7)[1]	10.0(18.4)[1]
IS 9751	21.0	38.2	49.7	6.3	7.6	8.9	4.0	5.3	6.4	5.7	5.0	4.3	70.0(57.0)	30.0(33.0)	20.0(26.6)
IS 19471	26.1	39.7	53.2	6.0	6.9	8.4	4.0	5.1	6.2	6.3	6.3	5.7	53.3(46.9)	33.3(35.2)	33.3(35.2)
IS 19624	33.1	51.5	66.3	5.9	7.9	8.8	3.9	5.5	6.4	3.7	3.0	2.3	36.7(36.9)	26.7(31.0)	23.3(28.1)
IS 19652	34.3	33.7	55.2	6.7	7.9	8.9	4.5	5.3	6.5	7.0	6.3	5.0	26.7(31.0)	20.0(26.1)	16.7(23.9)
IS 22498	24.0	38.6	52.0	5.7	6.9	7.7	3.7	4.8	5.7	4.3	5.0	4.3	56.7(48.8)	16.7(23.4)	13.3(21.1)
IS 22806	25.2	38.1	52.8	5.5	6.5	7.7	3.7	5.3	5.7	7.0	7.0	6.3	66.7(54.8)	43.3(41.1)	40.0(39.1)
IS 25041	29.8	36.2	54.2	6.1	7.2	8.3	4.2	4.9	6.5	5.0	5.0	3.7	43.3(41.2)	10.0(18.4)	6.7(12.3)
Mean	27.6	40.5	55.0	6.1	7.3	8.5	4.1	5.1	6.3	5.5	5.3	4.4	50.0(45.0)	24.2(28.2)	20.4(25.6)
SE(±)	2.49**	4.83NS	4.2*	0.86NS	1.0NS	1.7NS	0.7NS	0.6NS	0.5NS	0.81**	0.90NS	0.38NS	6.8(4.1)***	7.5(6.0)**	6.2(4.9)**
CV(%)	11.2	14.6	9.3	17.3	17.2	24.8	21.6	15.5	18.1	18.0	26.5	29.8	16.6(11.8)	37.9(25.8)	37.0(35.0)
$LSD_{0.05}$	7.6		12.7							2.5			20.6(12.4)	22.7(18.2)	18.8(14.8)

1 · Angular transformation.

***= Significant at 0.1% , **=Significant at 1%, *=Significant at 5% level, and NS=not significant.

significant differences in percent deadheart in the three age groups (Figs. 12 and 13). For comparison between the three age groups, results showed significant differences (P=0.01) in percent deadheart between 14 and 21, and; 14 and 28-day old tillers. No significant differences were recorded in percent deadheart between 21 and 28- day old tillers (Appen. H). Also results of the studies showed significant correlation between deadheart formation and height of tiller of 14-day old (-0.49), and between deadheart formation and boot stage for 21 and 28- day old tillers, which were 0.41 and 0.51, respectively (Appen. G). These values increased to 0.46, but within the same level of significance (P=0.05), for 21-day old tillers, and to 0.55 (P=0.01) for the 28 day-old by excluding the line IS 25041 which is a late maturating (Appen. G).

Rate of Tiller Growth

No significant differences were recorded in tiller growth at 4, 8, 12, and 16 days after tiller appearance (Fig. 14 and Appen. K). However, significant differences (P=0.05) were recorded in tiller length at 20 and 24 days after tiller appearance.

Fate of Tillers Under Infestation

The results are presented in table 6, fig. 15, and appens. L and M. The results showed that apart from deadheart caused by <u>Chilo</u> damage and breakage of juvenile tillers, natural death of tillers also occurred. Shoot fly attack of tillers was also recorded.

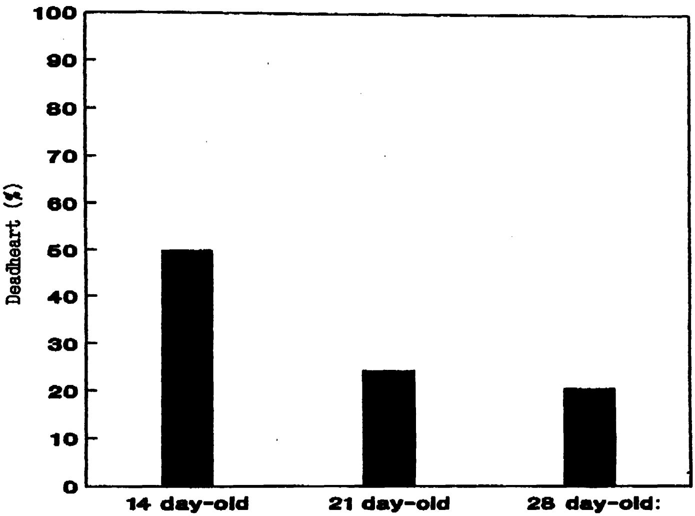


Figure 12. Deadheart in tillers of 14, 21, and 28-day old: Postrainy season.

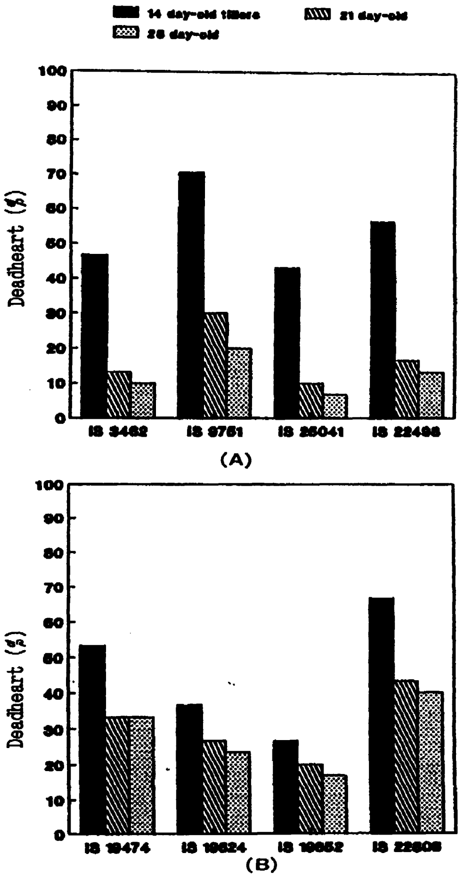


Figure 13. Deadheart in tillers of 14, 21, and 28-day old in the eight lines: Postrainy season.

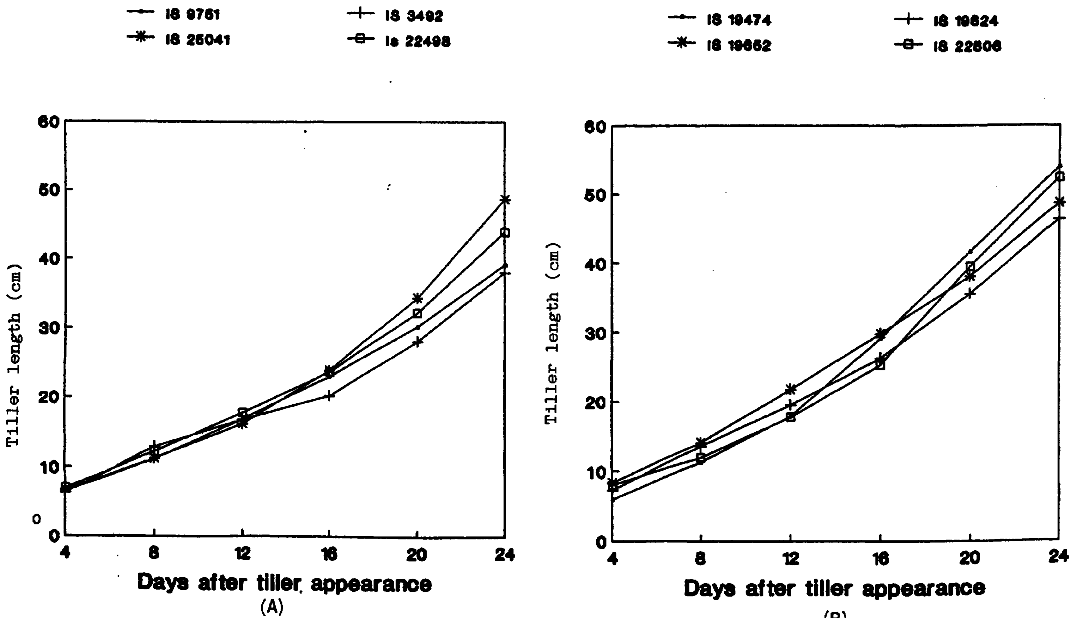


Figure 14. Tiller growth: Post-rainy season. (A) IS 3492, IS 9751, IS 25041, and IS 22498. (B) IS 19474, IS 19624, IS 19652, and IS 22806.

Table 6. Fate of tillers (tillers/20 plants) under *C. partellus* infestation: postrainy season.

A. Natural tiller mortality

Sorghum line	Treatments T1	T2	T3	Mean
IS 3492	24.7	1.3	0.7	8.9
IS 9751	21.0	1.0	0.7	7.6
IS 19474	21.0	5.7	4.3	10.3
IS 19624	20.7	6.0	3.7	10.1
IS 19652	16.7	2.7	1.7	7.0
IS 22498	10.0	5.3	6.0	7.1
IS 22806	25.3	8.0	6.7	13.3
IS 25041	21.7	8.3	5.7	11.9
Mean	20.1	4.8	3.7	9.5

	SE(±)	CV(%)	$LSD_{0.05}$
For comparing treatments	0.684^{***}	12.4	2.7
For comparing genotypes	0.794^{***}	25.0	2.3
For comparing treat. x Gen. (within same level of treat.)	1.376^{***}	25.0	1.1
For comparing treat. x Gen. (across treatment)	1.457^{***}	25.0	1.3

B. Immature tillers

Sorghum line	Treatments T1	T2	T3	Mean
IS 3492	10.7	8.7	11.3	10.2
IS 9751	13.3	9.3	5.7	9.4
IS 19474	10.7	9.7	16.0	12.1
IS 19624	0.7	7.7	6.7	5.0
IS 19652	10.7	12.7	18.3	13.9
IS 22498	12.7	3.3	24.7	13.6
IS 22806	11.7	8.3	17.0	12.3
IS 25041	17.0	5.7	7.7	13.4
Mean	10.7	8.2	14.7	11.3

	SE(±)	CV(%)	$LSD_{0.05}$
For comparing treatments	1.01^{*}	15.6	3.9
For comparing genotypes	1.20^{***}	32.2	3.5
For comparing treat. x Gen. (within same level of treat.)	2.09^{***}	32.2	6.1
For comparing treat. x Gen. (across treatment)	2.20^{***}	32.2	6.4

Contd..

Contd ..

C. Productive tillers

Sorghum line	Treatments T1	T2	T3	Mean
IS 3492	45.7	54.7	45.3	48.6
IS 9751	30.7	40.3	30.0	33.7
IS 19474	10.7	21.0	23.7	18.4
IS 19624	0.7	22.7	23.7	15.7
IS 19652	14.3	34.0	33.0	27.1
IS 22498	12.0	33.3	27.7	24.3
IS 22806	4.0	16.3	17.7	12.7
IS 25041	36.0	51.0	36.3	41.1
Mean	19.3	34.2	29.7	27.7

	SE(±)	CV(%)	$LSD_{0.05}$
For comparing treatments	0.824^{***}	5.1	3.2
For comparing genotypes	2.59^{***}	28.0	7.4
For comparing treat. x Gen. (within same level of treat.)	4.49^{NS}	28.0	
For comparing treat. x Gen. (across treatment)	4.28^{NS}	28.0	

D. Stem borer deadheart[1]

Sorghum line	Treatments T2	T3	Mean
IS 3492	68.3	65.7	67.0
IS 9751	69.0	64.7	66.8
IS 19474	9.3	23.0	16.2
IS 19624	8.3	19.7	14.0
IS 19652	10.0	12.7	11.3
IS 22498	11.3	17.3	14.3
IS 22806	8.0	18.7	13.3
IS 25041	44.0	49.3	46.7
Mean	28.5	33.9	31.2

	SE(±)	CV(%)	$LSD_{0.05}$
For comparing treatments	0.94^{NS}	5.2	
For comparing genotypes	2.89^{**}	22.7	8.4
For comparing treat. x Gen. (within same level of treat.)	4.09^{NS}	22.7	
For comparing treat. x Gen. (across treatment)	3.94^{NS}	22.7	

1 - Resulted from comparing T2 & T3.

Contd..

Contd..

E. Tiller breakage[1]

Sorghum line	Treatments T2	T3	Mean
IS 3492	9.3	15.3	12.3
IS 9751	16.0	8.3	12.2
IS 19474	21.0	5.7	4.3
IS 19624	22.3	22.3	22.3
IS 19652	24.7	23.3	24.0
IS 22498	27.7	26.0	26.8
IS 22806	16.7	24.3	20.5
IS 25041	23.7	15.7	19.7
Mean	20.0	19.6	19.8

	SE(±)	CV(%)	$LSD_{0.05}$
For comparing treatments	2.145^{NS}	18.8	
For comparing genotypes	1.827^{***}	22.6	5.3
For comparing treat. x Gen. (within same level of treat.)	2.584^{*}	22.6	7.5
For comparing treat. x Gen. (across treatment)	3.23^{*}	22.6	9.4

1 = Resulted from comparing T2 and T3.

F. Shoot fly deadheart

Sorghum line	Treatments T1	T2	T3	Mean
IS 3492	14.7	14.3	10.7	13.2
IS 9751	12.7	14.0	24.3	17.0
IS 19474	16.3	15.7	13.0	15.0
IS 19624	6.7	7.0	9.0	7.6
IS 19652	8.7	9.3	9.7	9.2
IS 22498	13.0	10.3	11.0	11.4
IS 22806	14.7	16.3	14.0	15.5
IS 25041	6.7	5.7	18.7	10.3
Mean	11.7	11.6	13.8	12.3

	SE(±)	CV(%)	$LSD_{0.05}$
For comparing treatments	1.45^{NS}	20.4	
For comparing genotypes	1.28^{***}	31.2	3.7
For comparing treat. x Gen. (within same level of treat.)	2.22^{**}	31.2	6.4
For comparing treat. x Gen. (across treatment)	2.53^{***}	31.2	7.3

T1 = Control treatment, T2 = Main stem infestation,
T3 = Main stem with tiller infestation.
***= Significant at 0.1%, **=Significant at 1%, *= Significant at 5% level, and NS=not significant.

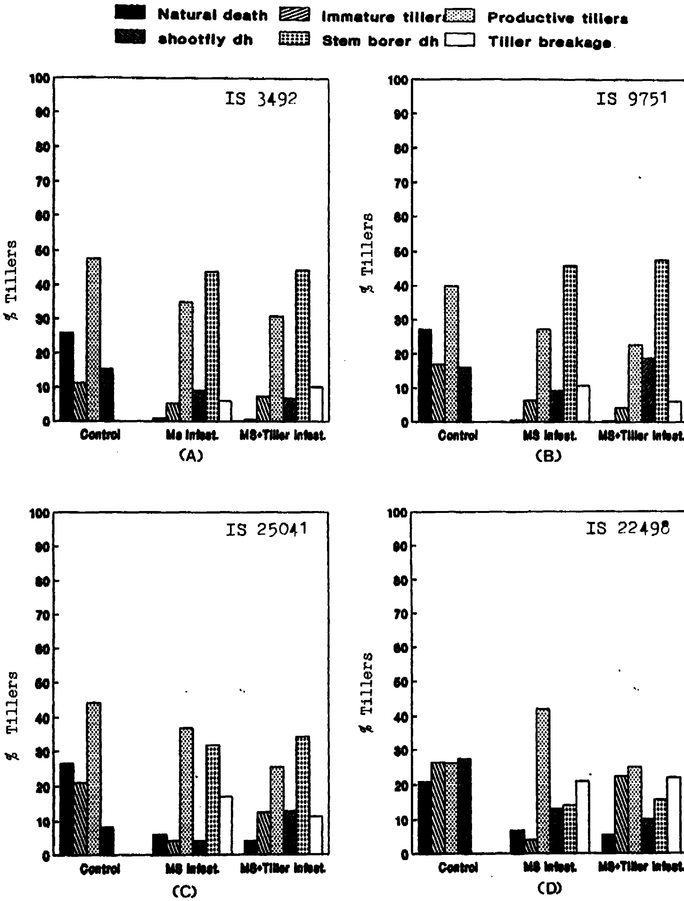


Figure 15. Fate of tillers under infestation in the individual lines : Post-rainy season.

dh= deadheart

MS=Main stem

Infest.= Infestation

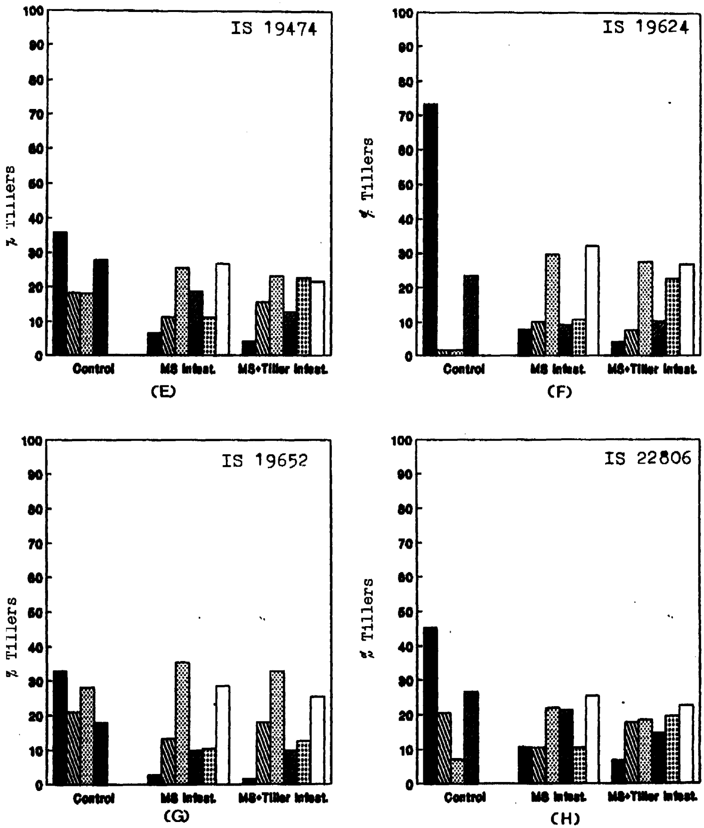


Figure 15 continued.

Natural tiller mortality

The results showed highly significant differences between treatments and genotypes in natural tiller mortality (Table 6A). Also the interactions between the treatments and genotypes were highly significant. The highest percentage of natural tiller mortality in the control treatment was recorded in IS 19624 (73.2) and the lowest (20.9) was recorded for IS 22498 (Figs. 15D and 15F). There was no significant differece between **treatments** 2 **and** 3 in natural tiller mortality.

Immature tillers (non-productive)

Significant differences were recorded between treatments in number of immature tillers. The highest number was recorded in the main stem and tiller infestation treatments. However, highly significant differences were obtained between lines. **The interactions** between the genotypes and treatments were highly significant (Table 6B).

Productive tillers

The results showed highly significant differences in number of productive tillers between treatments as well as genotypes. The line IS 3492 showed the highest number of productive tillers in the three treatments (Table 6C). No significant differences were recorded between treatment 2 and 3. Line IS 19624 showed the lowest percentage of productive tillers (1.7; Fig. 15F).

Stem borer deadheart

No significant differences were recorded between treatments in stem borer deadheart. However, the results indicated significant differences between the lines. The interaction between treatments and genotypes were not significant (Table 6D).

Tiller breakage

No significant differences were observed between treatments in tiller breakage caused by C. partellus, whereas highly significant differences were recorded between the lines. The results also showed significant interaction between genotypes and treatments (Table 6E).

Highly significant negative correlations were recorded between percent tiller breakage and number of tillers produced in the control treatment (r= -0.92). Percent tiller breakage was also correlated with angle of tiller (r= -0.81, Appen. G).

Shoot fly deadheart

Infestation by shoot fly was similar in all treatments. The lines were significantly different in the extent of shoot fly damage (Table 6F).

Grain Yield

Grain yield data are presented in table 7, and appens. N and O. Highly significant differences were recorded in total grain yield between treatments and genotypes. The interaction between genotypes and treatments were also highly significant (Figs.16 and 17).

Table 7. Total grain weight: postrainy season.

Sorghum line	Treatments (g /20 plants) T1	T2	T3	Mean
IS 3492	666.3	484.1	363.5	504.6
IS 9751	623.6	356.1	290.3	423.3
IS 19474	479.5	432.9	316.3	409.6
IS 19624	615.8	551.2	616.1	594.4
IS 19652	755.8	749.4	660.3	721.9
IS 22498	491.0	328.3	289.9	369.7
IS 22806	433.6	324.6	320.4	359.5
IS 25041	556.7	402.8	365.6	441.7
Mean	577.8	453.7	402.8	478.1

	SE(±)	CV(%)	$LSD_{0.05}$
For comparing treatments	15.67**	5.7	61.1
For comparing genotypes	20.80***	13.1	60.3
For comparing treat. x Gen. (within same level of treat.)	36.03**	13.1	104.5
For comparing treat. x Gen. (accross treatments)	37.17**	13.1	107.8

T1 = Control treatment, T2 = Main stem infestation,
T3 = Main stem with tiller infestation.

***=Significant at 0.1% , **=Significant at 1% level .

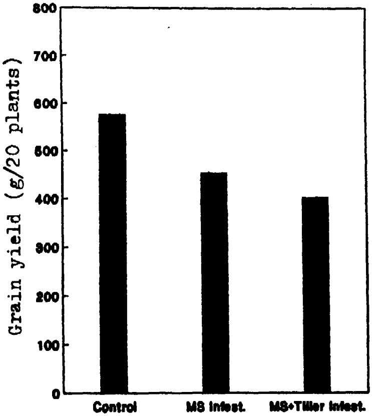


Figure 16. Overall total grain yield: Post-rainy season.

MS = Main stem

Infest. = Infestation

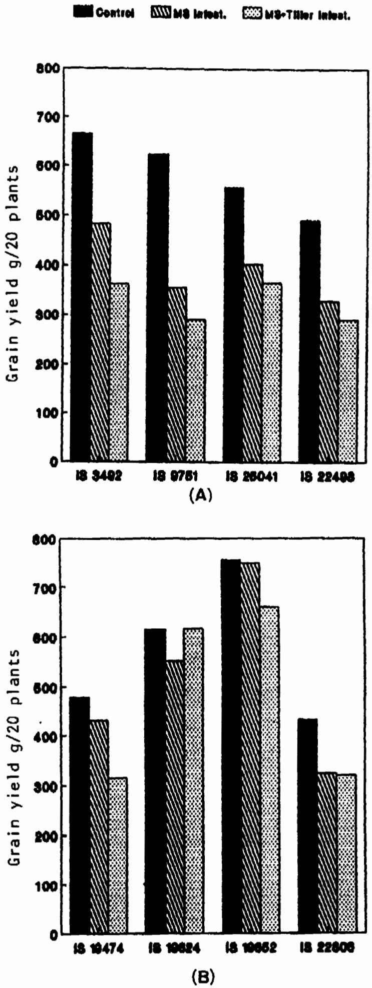


Figure 17. Total grain yield in the eight sorghum lines: Post-rainy season.
MS = Main stem
Infest. = Infestation

Significant correlation was recorded between percent contribution of tillers in total grain yield and total number of tillers in the control treatment (r=0.72; Appen. G). However, no significant correlations were recorded between percent contribution of tiller in grain yield and number of tillers in the infested treatments. Percent reductions in grain yield due to infestation by stem borer is shown in appen. O. However, the results also showed non-significant correlation between percent reduction in grain yield in the infested treatments and deadheart formation in the main stem (Appen. G).

RAINY SEASON STUDIES

Main Stem

Significant differances were detected between the lines with regard to stem height, leaf-feeding, and angle of tiller (Table 8). Excluding the checks, the lowest leaf-feeding score (5.7) was recorded for the lines IS 25041 and IS 9751. The largest angle of tiller was recorded for IS 9751 (33.9), whereas the smallest was recorded for IS 22498 and IS 22806 (19.5). The differences between the lines in time of deadheart appearance were not significant. Highly significant differences were recorded between the lines in percent deadheart (Table 8; Fig. 18). The highest deadheart formation was recorded in IS 19474 and IS 22806, whereas the lowest in IS 25041, excluding ICSV 700. No significant differences existed between deadheart formation in treatments 1 and 2. Significant correlations were recorded between deatheart formation and main stem height (Appen. P).

Table 8. Height of main stem at infestation, leaf-feeding score, **angle of** tiller, deadheart formation, and boot leaf stage: Rainy **season**.

Sorghum line	Height 15 DAE (cm)	Leaf-feeding Score	Angle of Tiller (degrees)	Date of Deadheart appearance	Deadheart (%) T2	Deadheart (%) T3	Boot Stage
IS 3492	37.4	7.7	32.7	30.7	36.7	53.3	38.0
IS 9751	41.7	5.7	33.9	29.1	46.7	53.3	38.3
IS 19474	35.8	7.7	21.3	30.3	96.7	90.0	60.6
IS 19624	36.6	6.3	21.8	31.0	73.3	70.0	45.3
IS 19652	38.7	7.7	24.1	29.0	83.3	86.7	44.9
IS 22498	35.4	6.3	19.5	30.0	46.7	56.7	41.8
IS 22806	34.2	8.3	19.5	30.4	96.7	93.3	61.0
IS 25041	41.7	5.7	27.2	30.6	46.7	36.7	59.3
ICSV 700	39.3	1.7	-	31.3	20.0	23.3	56.0
CSH 1	44.0	7.7	-	29.9	73.3	83.3	42.9
Mean	38.5	6.5	24.9	30.2	62.0	64.7	49.7
SE (±)	1.5**	1.0*	2.4***	1.4 NS	6.2***	7.5***	0.8*
CV (%)	4.9	19.0	11.6	5.5	12.1	14.2	2.0
LSD 0.05	4.5	3.0	7.2		18.6	22.5	2.4

DAE= Days after emergence, T2= Main stem infestation, and T3= Main stem with tiller infestation.

*****= Significant at 0.1% , **=Significant at 1%, *= Significant at 5% level, and NS=not significant.**

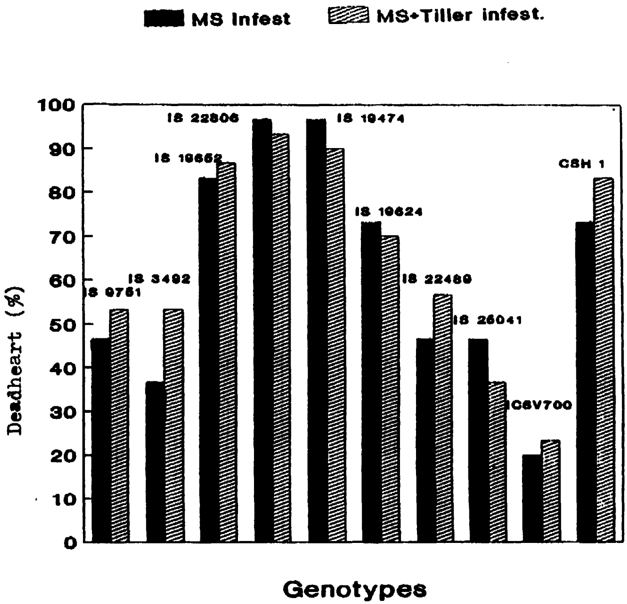


Figure 18. Deadheart formation in the main stem: Rainy-season.

MS = Main stem

Infest. = Infestation

The lines were significantly different with regard to the time of boot stage appearance. In IS 3492 and IS 9751 boot stage appeared early, whereas ICSV 700 was the latest. Significant correlation was obtained between boot stage and deadheart formation in treatment 2 (r=0.62; Appen. P). However, the correlation between boot stage and deadheart formation in treatment 3 was not significant.

Total Number of Basal Tillers

Highly significant differences were recorded in number of tillers between treatments and genotypes (Appen. Q; **Figs.** 19 and 20). Plates 13 and 14 show tiller production in the control and infested treatments at 56 DAE. The interaction between genotypes and treatments was significant. The correlations between the number of tillers produced and deadheart formation are significant (Appen. P).

Pattern of Tiller Appearance Under Infestation

Results are presented in appen. R; and **figs.** 21 and 22. Tiller appearance occurred before infestation in all lines, except ICSV 700 and CSH 1 where more or less no tiller production before infestation was reported (Plate 15). In all lines tiller production ceased just after infestation and resumed only after deadheart formation.

Leaf-feeding, Deadheart Formation, and Boot Leaf Stage in Tillers

Results are presented in appen. S. Significant differences existed between the lines in deadheart formation

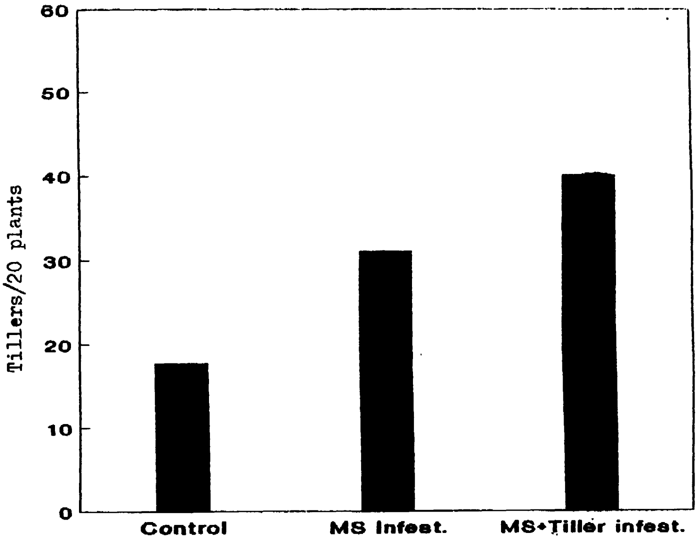


Figure 19. Overall tiller production: Rainy season.

MS = Main Stem

Infest. = Infestation

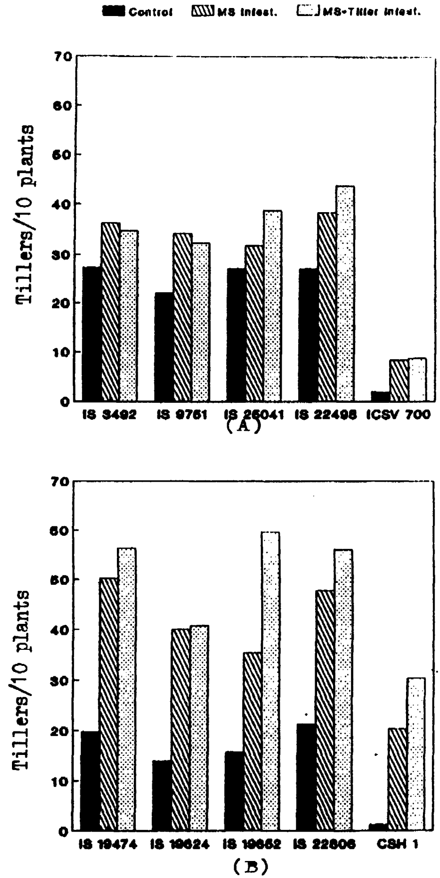


Figure 20. Tiller production in individual lines: Rainy season.

MS = Main stem
Infest. = Infestation

(A)

(B)

Plate 13. Tiller production in the control treatment recorded at 56DAE: Rainy season.

(A)

(B)

Plate 14. Tiller production in the infested treatment recorded at 56DAE: Rainy season.

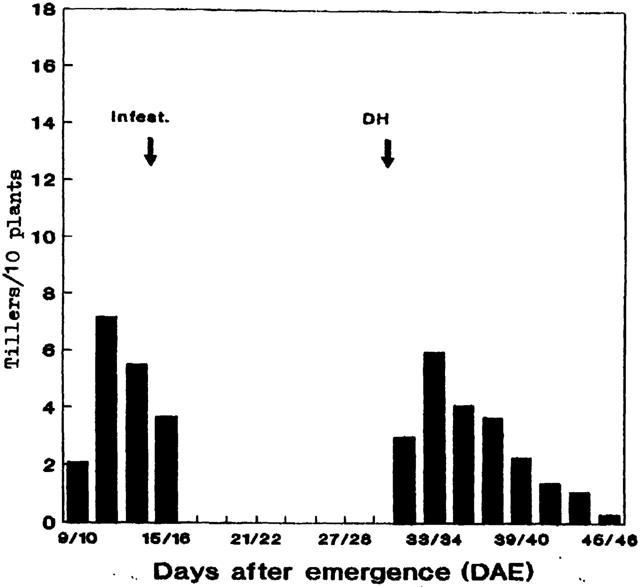


Figure 21. Pattern of tiller appearance under *C. partellus* infestation: Rainy season.

DH = Deadheart
Infest. = Infestation

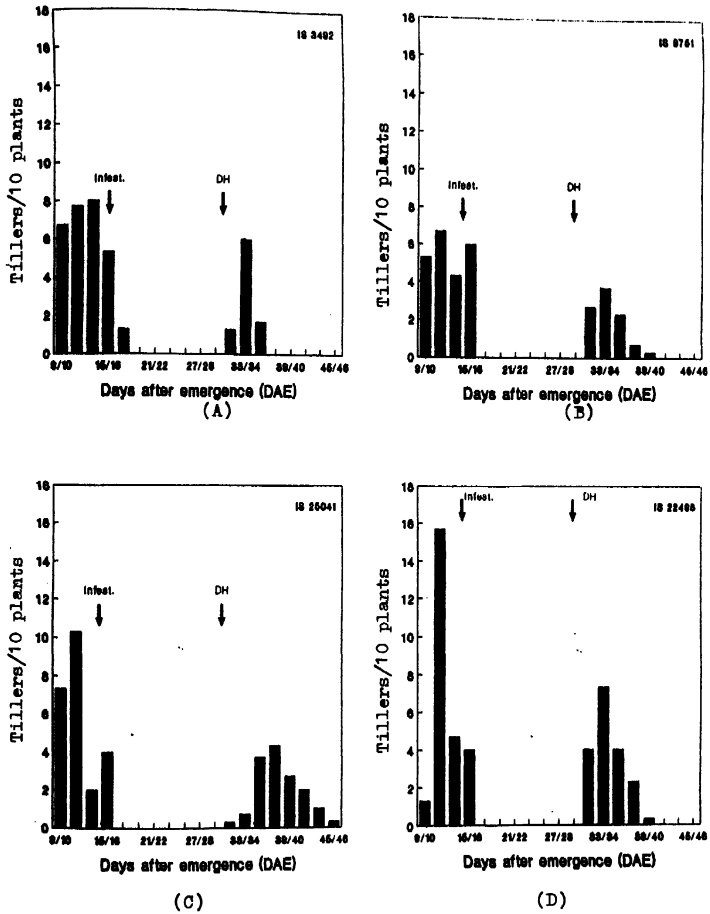
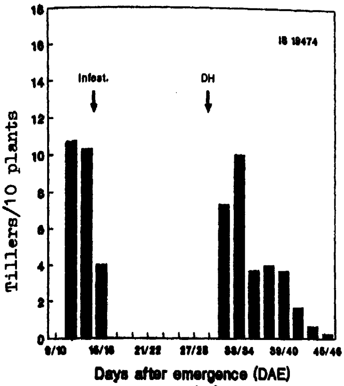
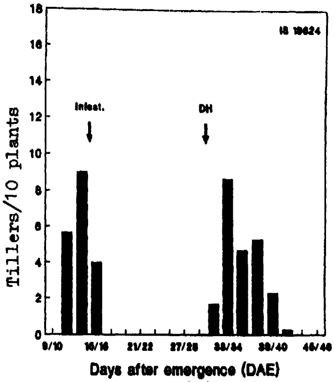


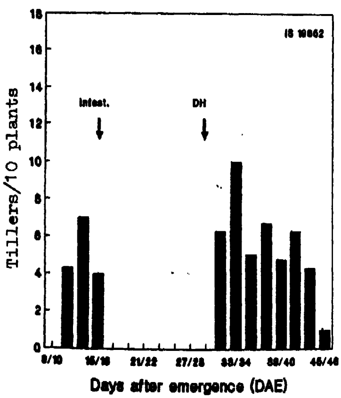
Figure 22. Pattern of tiller appearance under C. partellus infestation in the individual lines : Rainy season.
DH = Deadheart
Infest. = Infestation



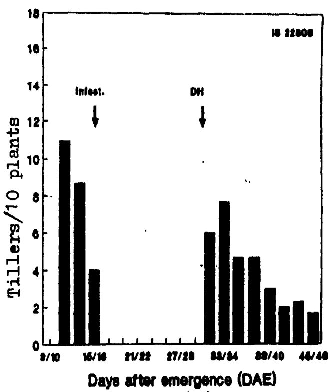
(E)



(F)

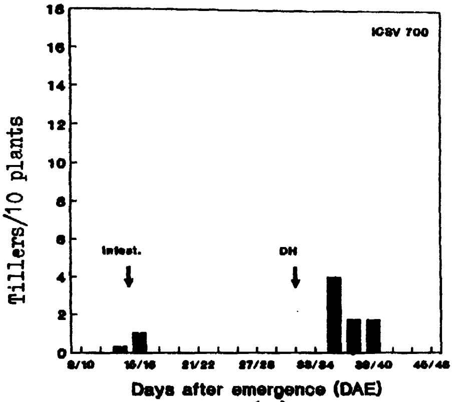


(G)

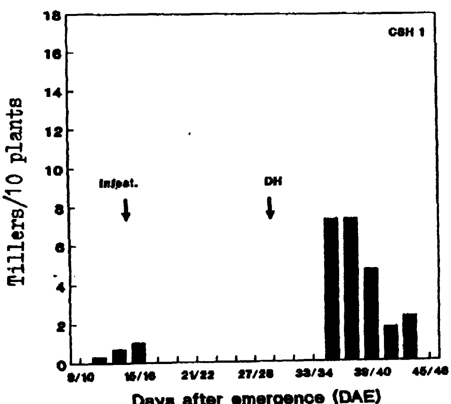


(H)

Figure 22 continued.



(I)



(J)

Figure 22 continued.

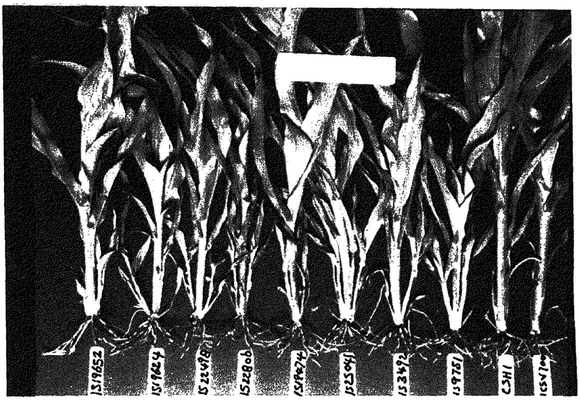


Plate 15. Tillering at infestation (15DAE): Rainy season.

in 14 day-old tillers. Also the differences between the lines in time of boot stage appearance were highly significant. The results also showed significant differences between main stem and tillers in time of boot stage appearance. Significant, negative correlation (r= -0.47) existed between tiller length at 24-day old (in control treatment) and deadheart formation in 14-day old tillers (Fig. 23).

Rate of Tiller Growth

Results of tiller growth from the control and deadheart plants in the infested treatment are presented in appen. T and fig. 24. The highest tiller growth in the control were those of lines IS 3492 and IS 9751, whereas in the infested treatment the highest growth was that of the lines IS 19474, IS 22806, and IS 25041.

Fate of Tillers Under Infestation

The overall fate of tillers under *C. partellus* infestation is presented in fig. 25. Most of the tillers died naturally in the control treatment. In the infested treatments, most of the stem borer damage in tillers was made through deadheart formation and negligable part was damaged through breakage.

Grain Yield

Data related to grain are given in table 9 and appens. U and V. Highly significant differences were recorded in total grain yield between genotypes and treatments (Figs. 26 and 27). Significant correlations were recorded between

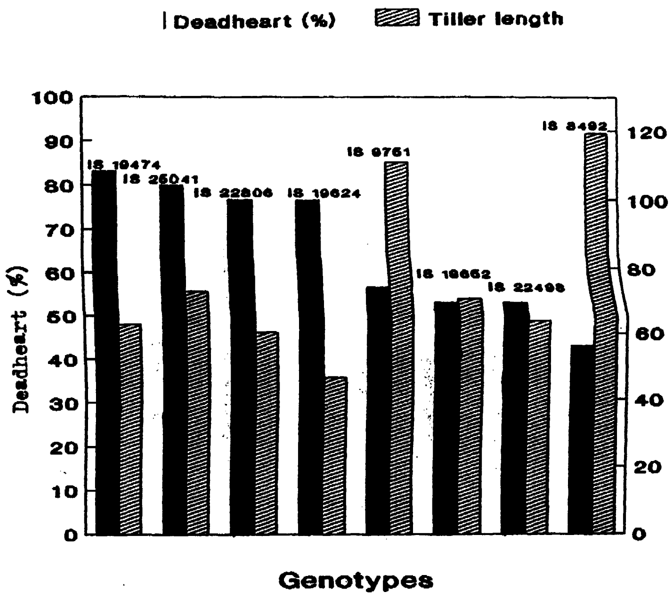


Figure 23. Relationship between tiller length (24-day old) in the control treatment and percent deadheart in tillers 14-day old: Rainy season.

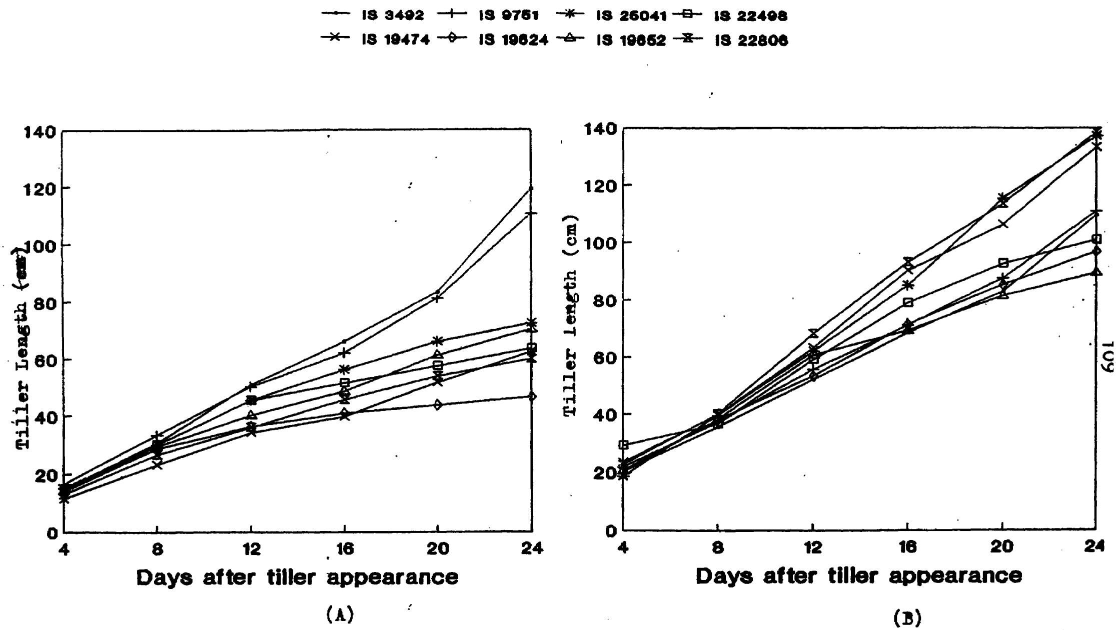


Figure 24. Tiller growth in rainy season. (A) Control, (B) Infested treatment.

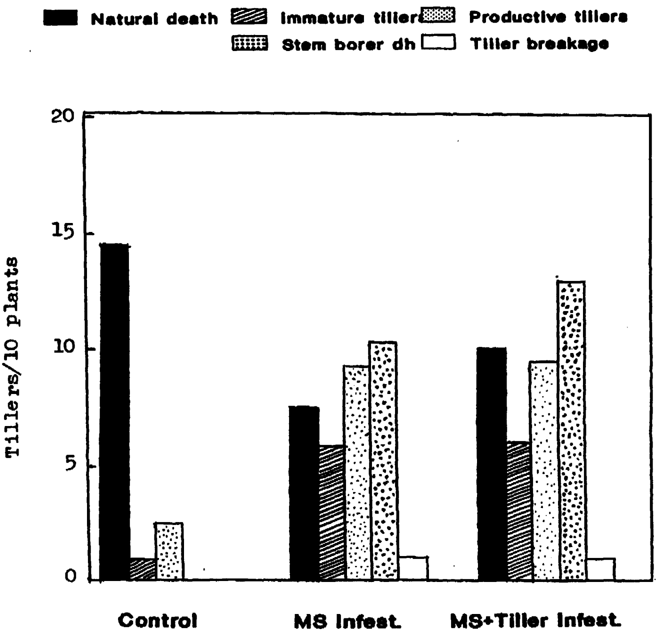


Figure 25. Overall fate of tillers under C. partellus infestation: Rainy season.

dh = deadheart
MS = Main stem
Infest.=Infestation

Table 9. Total grain weight (g/10 plants): Rainy season.

Sorghum line	Treatments T1	T2	T3	Mean
IS 3492	399.3	180.7	182.7	254.2
IS 9751	260.5	135.6	152.3	182.8
IS 19474	280.6	147.8	150.3	192.9
IS 19624	351.9	222.2	193.8	256.0
IS 19652	429.8	190.9	133.7	251.0
IS 22498	250.8	163.2	180.4	198.1
IS 22806	347.4	182.0	117.8	215.7
IS 25041	212.4	174.1	153.3	179.9
ICSV 700	127.6	101.6	96.8	108.7
CSH 1	418.0	117.4	91.0	208.8
Mean	307.8	161.6	145.2	204.9

	SE (±)	CV (%)	LSD 0.05
For comparing treatments	8.2**	4.9	32.5
For comparing genotypes	16.4**	17.0	46.4
For comparing treatment x genotype (within same level of treatment)	28.4**	17.0	80.3
For comparing treatment x genotype (across treatments)	28.1**	17.0	79.5

T1= Control, T2= Main stem infestation, and T3= Main stem with tiller infestation.

**=Significant at 1% level.

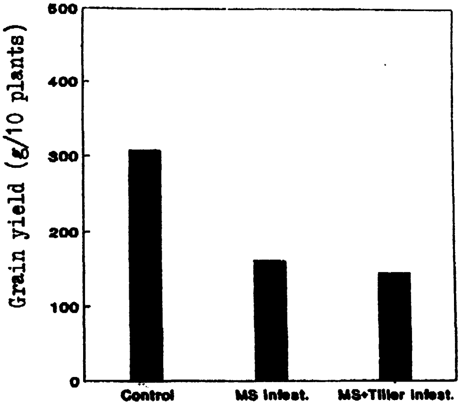


Figure 26. Overall total grain yield: Rainy season.
MS = Main Stem
Infest. = Infestation

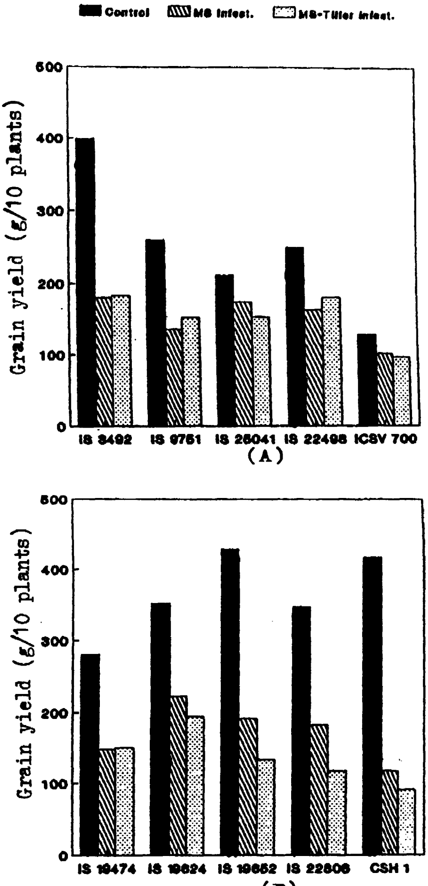


Figure 27. Total grain yield in the Individual lines : Rainy season.
MS = Main stem
Infest. = Infestation

deadheart formation and number of tillers produced (Appen. P). Also, significant positive correlations were recorded between deadheart formation and percent reduction in grain yield in treatment 3 and mean of the two treatmets. However, the correlation coefficient for treatment two was not significant (Appen. P).

SEASONAL EFFECTS

Total Number of Basal Tillers

Results of the combined analysis of the two seasons showed significant differences in number of basal tillers per plant (Appen. W).

Pattern of Tiller Appearance Under *Chilo* Infestation

The overall pattern of tiller appearance under *C. partellus* infestation in the two seasons and the minimum temperature recorded during the period are presented in fig. 28.

Fate of Tillers Under Infestation

Results of the overall fate of tillers under *C. partellus* infestation in the two seasons are presented in fig. 29. Considerable differences existed between the two seasons. The differences were extremely pronounced in natural tiller mortality. A mortality value of 36.0% was recorded in the post-rainy season, whereas in the rainy season the percentage was 86.3. Also great differences were recorded in tiller breakage between the two seasons.

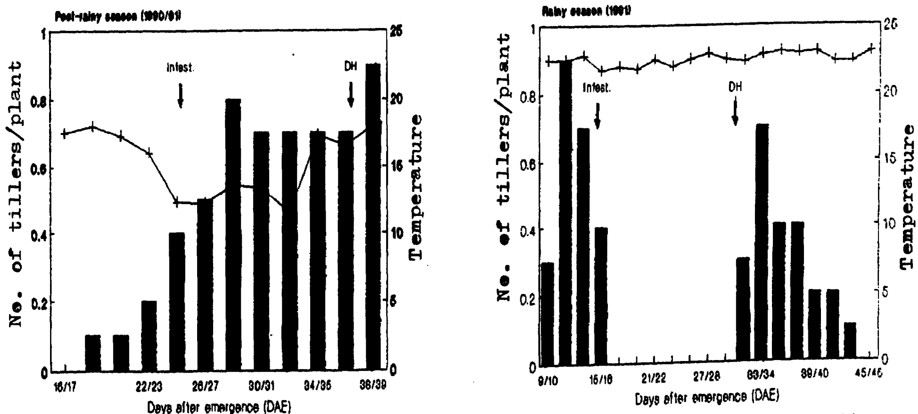


Figure 28. Overall pattern of tiller appearance under C. partellus infestation and minimum temperature recorded at the two seasons. ■, pattern of tiller appearance. —+—, temperature.

DH = Deadheart

Infest. = Infestation

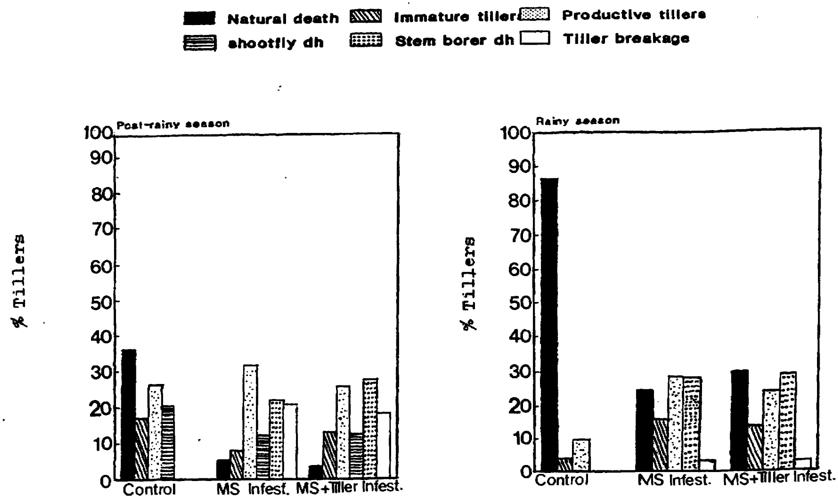


Figure 29. Overall fate of tillers under C. partellus infestation in the two seasons.

dh = deadheart
MS = Main stem
Infest. = Infestation

Percent Contribution of Tillers in Total Grain Yield

Results are presented in appen. X. and figs. 30 and 31. Seasonal differences were significant. Differences between treatments and genotypes were also significant.

INSECT-INDUCED TILLERING

Results are presented in appen. Y. and fig. 32 and Plates 16 and 17. Differences in number of tillers between control and infested; and control and mechanical damage were highly significant. Significant differences ($P = 0.05$) were also recorded between insect infested and mechanically damaged plants.

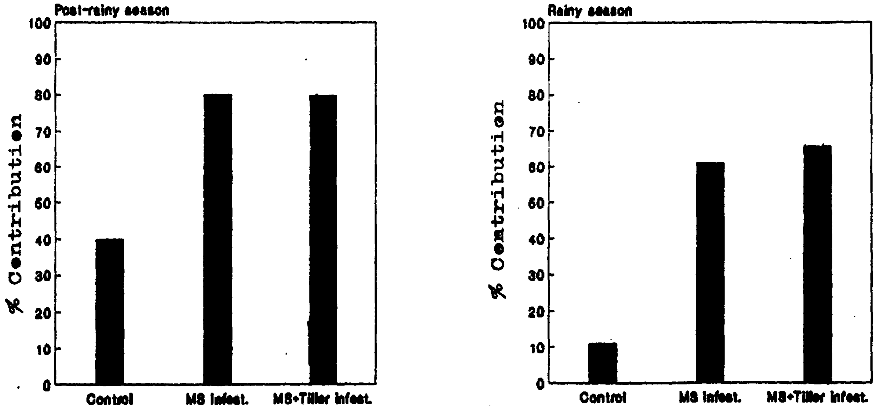


Figure 30. Percent Contribution of tillers in total grain yield.

MS = Main Stem

Infest.= Infestation

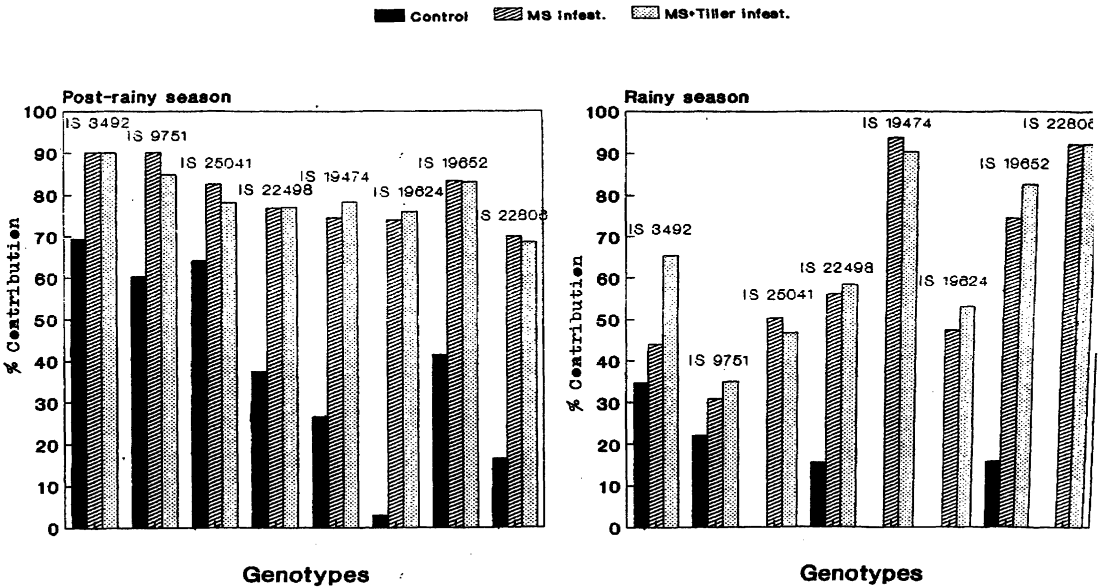


Figure 31. Percent contribution of tillers in total grain yield in Individual lines.

MS = Main stem

Infest. = Infestation

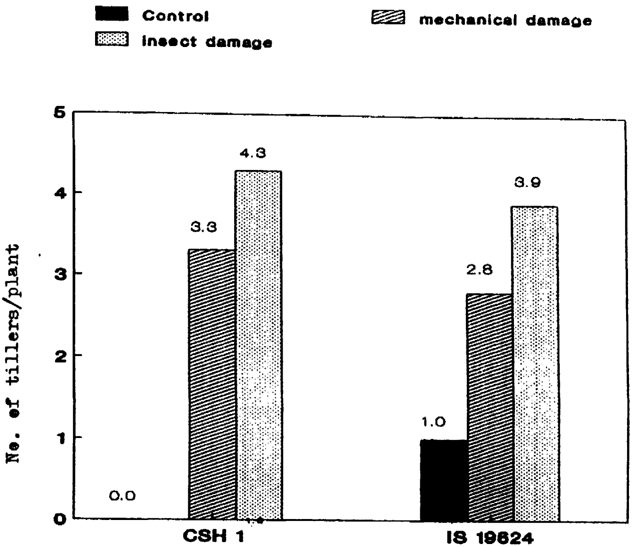
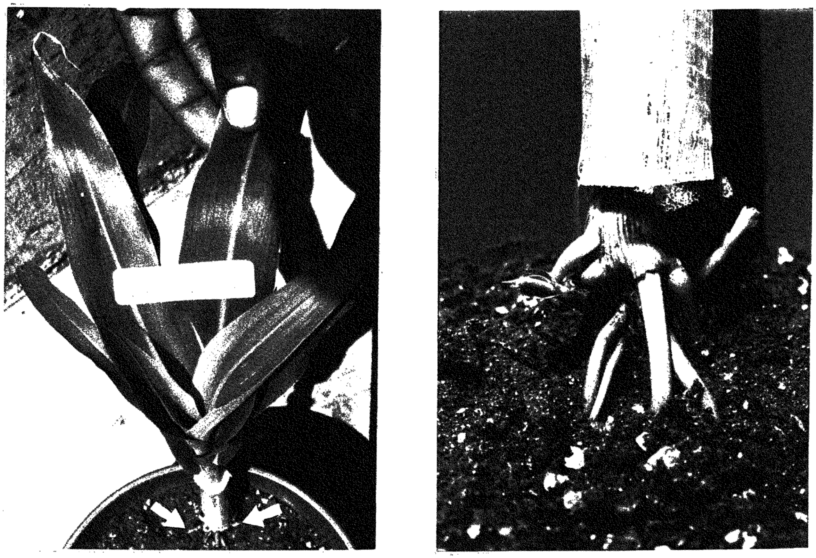


Figure 32. Result of experiment on insect-induced tillering.



(A) (B)

Plate 16. Projection of basal tillers in CSH1 in infested but non-deadheart plant.

(A) whole plant with projected tillers.

(B) The projected basal tillers magnified.

Plate 17. Control and infested, but non-deadheart plant of IS 19624 showing better growth in the infested one.

DISCUSSION

The present trend in modern agriculture is directed towards maximizing crop production. This is vividly exemplified by the development and production of improved varieties and hybrids which are evolutionary negatively correlated with tillering. In sorghum, **most of the hybrids were** selected specifically for lack of tillering to suit modern mechanized agriculture. In the present studies tiller prodution in the hybrid CSH 1 and IS 19624 occured, more or less, after deadheart formation supporting the aforementioned idea and conforming Sharma's et al ,(1977) findings. Accordingly basal tillering was a consequence of termination of the main stem due to deadheart formation. Under poor-resource conditions of the semi-arid tropics a character like strong tillering ability can be of great value as an insurance against biotic and abiotic stresses.

The results of the initial screening of the accessions manifested by the frequency distribution of recovery scores suggested the polygenic control of the recovery after insect attack in sorghum. The sample size used was insufficient for obtaining line or lines with score 1 (excellent recovery). Also, tillering or growth of axillary buds usually occurs following the release from apical dominance by the action of the insect (Leüschner, 1989) which can justify not obtaining lines with very poor recovery (score 9). Moreover, most of these lines are unimproved traditional cultivars, which may exhibit tillering capacities even without infestation and/or deadheart formation. This was evidently clear from the findings of the field studies done on the selected eight lines. However, the effect of deadheart formation on tiller production was very obvious from the results of glasshouse and field evaluation studies. The positive significant correlation between number of tillers produced after deadheart formation and total number of tillers obtained from glasshouse studies, was an evidence for this effect. Under rainy season conditions, extent of tiller production (or plant recovery) depends on level of deadheart formation or "primary resistance". This finding is supported by the significant correlation between number of tillers produced and percent deadheart and in agreement with that of Sharma et al(1977). The lack of this correlation under post-rainy conditions is mainly due to the effect of cool temperature in the induction of extra tillers which masked the effect of deadheart formation.

The results of the correlation between deadheart formation and maturity period under post-rainy season conditions, is in contradiction with that of Taneja and Woodhead (1989). However, in the rainy season the correlation was in conformity with that of the latter scientists, who associated rapid panicle initiation with resistance to C. partellus. Although IS 3492 and IS 9751 are early maturing, they showed relatively high degree of susceptibility to stem borer in post-rainy season. Extensive tillering may be one of the reasons contributing in masking the effect of rapid maturation in stem borer resistance. The main stem may be weakened by the effect of this extensive tiller production. An interpretation that can be illustrated by using the postulation put forward by Milthorpe and Davidson (1966). They assumed that part of dry matter accumulating in the tillers is derived from the main shoot and not the product of photosynthesis of its own. Also, this dry matter might not be sufficient to sustain the amount of larvae used for infestation (7-8 larvae/plant). Due to the competition in the available food, the larvae may be enforced to disperse a little bit earlier than the normal situation resulting in deadheart formation. The low rate of plant growth due to cool temperature prevailing in the post-rainy season may also aggravate this effect. This may explain the exceptionally early appearnce of deadheart in IS 3492 and IS 9751 under post-rainy season conditions. On the other hand, the delayed appearance of deadheart in IS 25041 and the relatively low and stable deadheart formation are signs of the presence of "primary resistance" to the stem borer.

The differences in the angle of the tiller might have something to do with the extent of deadheart formation. This is obvious through the positive correlation between the angle and deadheart formation under post-rainy season conditions. This indicates that as tillers being in close contact to the main stem, there will be more chance for it to escape the attack of the larvae migrating from the upper parts of the plants. In this case, larvae will be attracted to these tillers, particularly if they are at their juvenile stages. As the angle becomes wider, chances for the attack of the main stem will also be higher. Another support also comes from the significant negative correlation between the angle and percent tiller breakage. Also the attraction of the larvae to the juvenile tillers may result in delay in their enterance inside the main stem. Accordingly, this will increase their chances of exposure to unfavorable environmental conditions and natural enemies. No doubt further research is warranted in this area.

Regarding natural tillering ability, three habits were noticed in the selected lines: (1) lines which are characterized by extensive tiller production (e.g. IS 3492), (2) lines which produce few early tillers which are retarded in their growth (e.g. IS 19624), and (3) lines form tillers which relatively not retarded in growth and IS 19652 is an example for this group. These are genotypic differences reflecting the differences in the strength in apical dominance among the lines. The angle of tiller, which appeared to be regulated by the activities of the apical bud, (Phillips, 1975) can also be used to reflect the strength of the apical dominance. The coincidence that the lines with the highest tillering ability were also highest in this angle can support this idea.

The effect of the stem borer on the increase in tiller production is very obvious in the significant differences between the control and the infested treatments. The effect occured through the attack and death of the meristematic tissues of the plant, which leads to deadheart formation. The release from apical dominance is not the only factor contributing to the increase in tiller production. The significant differences in tiller productivity between the two seasons can mainly be attributed to the differences in temperature (Downes, 1968; and Myers, 1986).

In addition to the genotypic (natural tillering) and environmental (viz.,temperature and deadhreart) effects on tillering under stem borer infestation, chances of extratillers induced by feeding activity of the insect are also there. The evidence arises from the results of insect-induced tillering. In these studies some of the infested plants respond by tillering (CSH 1) or better tiller growth (IS 19624) even before distinct deadheart formation. These results can be interpretted on the basis of mechanical or physiological reasons. The starting of feeding of larvae on the meristematic tissue may result in partially releasing the apical dominance permitting the extension of basal buds in the form of tillers. On the other hand, during feeding of the larvae a growth-regulator-substance may be present in the larval saliva which may stimulate tiller induction. This idea is supported by studies of Capinera and Roltsch (1980).

Research work should be initiated towards better understanding of the physiological and biochemical aspects of the insect/host plant relationship with respect to tillering and recovery resistance.

From the results of the pattern of tiller appearance under C. partellus infestation, tillers produced before infestation represented the natural tillering ability of the line. It coincided, more or less, with the number produced in the healthy plants. Under post-rainy season conditions, the decrease in the abilities of the lines to produce tillers is indicated by a general depression in the period between infestation and deadheart formation. The production of secondary tillers, due to the shoot fly attack during this period, resulted in making the depression more flatter than the expected. Under the rainy season conditions, the complete inhibition of tiller appearance between infestation and deadheart formation, can be mainly due to the temperature differences. The effect of cool temperature on pattern of tiller appearance can be traced through its weakening of the apical dominance.

The uniformity of tiller infestation among the lines used in the glasshouse screening suggested that the insects placed initially on the leaf whorl of the main stem are responsible for that. This attack either takes place by dispersal of the larvae directly from leaves to tillers or after their migration to the base of main stem, where it bores inside. Entry of the larvae inside the stem occurs at the soil level or a few centimeters above (Leüschner, 1989), where basal tillers also emerge. Also, since natural infestation by C.partellus at ICRISAT center is low (Taneja and Leüschner, 1985), this provides another proof for this explanation.

The reliance on tiller survival parameter for selection of the lines would be supported by their higher correlation coefficients with the recovery score. Plant recovery can be considered as a direct result of the ability of tillers to survive. The two parameters were not independant in determining resistance to shoot fly (Sharma et al,1977). This might explain the similarity between the correlation coefficients of the number of surviving tillers per plant and the percent recovered plants with the recovery score. Moreover, the high degree of correspondance between the distribution of the lines in the bivariate (percent tiller survival and recovery score) and multivariate (percent tiller survival, percent recovered plants, and recovery score) relationship can further support the same idea. In conclusion, it could be said that both parameters, percent recovered plants and percent tiller survival are convenient to be used as an indication for the recovery resistance to the stem borer and the shoot fly (Starks, 1970). Also, the present results suggested that both tillering capacity, expressed by the total number of tillers produced per plant and tiller survival ability are important for recovery resistance. However, the influence of the latter is more pronounced as indicated by its highest correlation with the recovery score.

Virtually, the existence of any factor related to tiller survival will be of great value in the mechanism of recovery resistance to the stem borer. Results of post-rainy season suggested presence of variabilities in certain factor(s) related to leaf-feeding preference or any antibiotic mechanism in tillers. This factor diminishes with age as the results indicated. For the shoot fly, lignification is probably a most important factor in tiller survival than silica (Blum, 1968 and 1969; and Doggett, 1988).

With regard to deadheart formation in tillers, the results suggested that at the early stages vigor of tillers is an important factor for their survival. With the progressive growth and development of tillers, the advantage converted to lines with early maturity which showed less deadheart formation. In this respect IS 25041 is an interesting exception. It manifested relatively low deadheart formation (in main stem and tillers) meanwhile it is late maturing. Again, this indicates the presence of "primary resistance" not related to maturation period in this line. Also the fact that tillers reach maturity faster than the main stem will provide more chances for their synchronization in head production. Moreover, the general observation indicates that tiller maturity period seems to be related to their place of origin (basal or axillary) and orders (primary, secondary, or tertiary).

This might be an interesting character in breeding for recovery resistance programs.

Since tiller growth in the post-rainy season was recorded from plants with or without deadheart formation, this created variabilities which may have resulted in masking some significant differences between the lines. The possible variation within the line in this character may also have contributed in this respect. Tiller growth under rainy season conditions is obviously related to the physiological condition of the plant (whether it is deadheart or not). Apical dominance is implicated here. This can also be reflected in the survival ability of tillers when exposed to stem borer infestation. Tillers when infested at 14 days after their appearance, they were under the effect of the main shoot dominance. Because at that time main stem was already infested but still no formation of deadheart. Consequently, lines with weak apical dominance (IS 3492 and IS 9751) will be exposed to less damage. On the other hand, tillers in lines with strong apical dominance (IS 19624) suffer more insect damage because of their growth retardation. For such lines, faster appearance of deadheart will be advantageous, because this results in quick relief of the stress exerted over these tillers by the apical meristem. The faster tiller growth recorded from deadheart plants and the relatively very low deadhearts percent in tillers of 21 and 28 day-old in IS 19474 and IS 22806 can further support this idea. In these two lines faster tiller growth seems to be associated with their survival, an observation recorded by Blum (1968) in his studies on the shoot fly.

Natural mortality as one of the components of fate of tillers under infestation, can also reflect strength of apical dominance. Line IS 19624 is considered to be the highest in this respect. The release from apical dominance through deadheart formation and the attack of larvae to tillers seem responsible for the differences between the control and the infested treatment in the natural death of tillers. Seasonal differences are attributed to differences in the prevailing temperature through the effect on tillering ability (Downes, 1968; and Myers, 1986). The fact that under the rainy season conditions, most of the stem borer damage occured through deadheart formation and only a negligible part as tiller breakage, can be attributed to better growth conditions, mainly temperature. These conditions allow the tillers to grow rapidly and vigorously providing good chances for the larvae to tunnel inside forming deadheart. Also tillers arising early possibly exert dominance over other primary or secondary ones, minimizing levels of juvenile tiller mortality. Contararily, the highest proportion of tiller breakage in the post-rainy season can be attributed to their continuous availability. Juvenile tiller breakage may provide an evidence that the larva blindly tend to bore inside the stem and that there is no feedback mechanism through which the insect is able to find the suitable stem diameter to bore inside. Such kind of behavior needs to be investigated as a loopehole in the dynamics of the insect/host plant relationship.

As indicated by Singh et al (1968) deadheart formation is considered the most stable parameter for distiguinshing levels of resistance (primary resistance). The effect of deadheart formation on grain yield can be traced through the significant negative relationship between them (Taneja and Leüschner, 1985). In the present studies, the relative susceptability of the lines were judged through the percent reduction in grain yield. In this respect the results suggested the independance of any yield reductions from the effect of deadhearts. The alteration of this relationship can be attributed to the compensatory mechanism(s) through the effective tillering. These findings were supported by Flattery (1982) who found that the inherent tillering ability in one line (cultivar 65 D) masked any yield reductions that might have resulted from attack by this pest. The results also indicate that, level of infestation (main stem or main stem with tiller infestation) and season (mainly temperature) have a role in modifying this relationship. Evidently, the effect of the season comes from the effect of low temperature on tiller induction (Downes,1968) and,in turn in the capacity of the plants to recover. However, for level of infestation further studies are warranted relating it to deadheart formation and ability of plants to express recovery resistance in terms of grain yield compensation.

The results reveal highest potential for tiller production in the post-rainy season and consequently more expression of recovery resistance. This judgement comes from the significant differences in percent contribution of tillers in total grain yield in the two seasons. In the post-rainy season, there is an association between natural tillering ability of the lines and the extent of their contribution in total grain yield. This association was lacking in infested plots implying that the number of tillers produced after infestation can not be taken as a measure for their contribution in grain yield. Accordingly, after infestation, tiller survivalship will be of a more importance than their numbers which already known to be associated with their age.

It is very convenient to consider certain interesting observations, where infestation by stem borer resulted in no yield reduction or even yield increment. In the post-rainy season and in IS 19652 less seeds were available for sowing which resulted in a little bit wider spaces between plants. The capacity of plants to tiller increases with the decrease in plant population (Escalada and Plucknett, 1975; Peacock and Wilson, 1984; and Schulze, 1971), this provided better chances of recovery in this line (IS 19652). More or less, there is no any yield decline in the main stem infestation treatment. This indicates that there is a big possibility of exploiting the interaction between tillering and plant population in managing sorghum stem borers. Research to be done in this area will be of vital importance. Moreover, the increase in grain yield in tiller infestation treatment of IS 19624 may be due to the elimination of some of the tillers, which may result in giving more chance for the remaining ones to produce vigorous and effective tillers. This is an observation frequently recorded in rice by some Japanese workers. It has been contended that infestation by gall midge at tillering phase does not interfere with the production; rather damage to non-productive tillers is helpful because nutrient drainage is restricted.

A last point of interest is that under field conditions, it is unlikely to find infestation by only one insect pest. A good example for that is the infestation inflicted by midge in post-rainy season which resulted in slight yield reduction. The lines IS 19474 and IS 22806 expressed some levels of midge resistance which was already reported by Sharma (1985). Accordingly, they can be very useful in multiple insect resistance programs which recently initiated by Nwanze et al., (1991).

CONCLUSION

The conclusions that can be generated from the present studies are as follows:

Firstly:

1. Pattern of tiller appearance in sorghum under C. partellus infestation and damage is determined by the natural tillering ability of the line, date of deadheart appearance, and season (mainly temperature effect).
2. Total tillering (total tiller production) under stem borer infestation can be grouped into:

a. Natural tillering ability which is an important factor in the mechanism of recovery resistance. This tillering ability, i.e extent of apical dominance, can be judged through a number of parameters:

   i. Total number of tillers produced.
   ii. Rate of tiller growth.
   iii. Natural tiller mortality.
   iv. Angle of tiller. This angle might have something to do with the escape from stem borer damage.

b. Tillering due to deadheart formation (release from apical dominance). This kind of tillering is more pronounced under rainy season conditions.

c. Tillering induced by low temperature effect.

d. Tillering induced by feeding activity of the insect itself (insect-induced tillering).

Secondly:

1. There is a possibility of existence of certain age factor(s) associated with insect preference to feed on leaves of tillers or any other antibiotic mechanism on them. The effect of this factor diminishes as tiller getting older.
2. In younger tillers, the vigor (height of tillers) is important for their survival. With aging the advantages converted to rapid maturation. On the other hand, the effect of rapid maturation of the main stem on its resistance to stem borer may depend on several factors. The genotype (tillering ability) and the season are among the most important. The effect of season is mainly through temperature in induction of more tillers. Since tillers mature earlier than the main stem, the chance of synchronization of both of them in head production is also there.
3. Tiller survival ability is an essential factor in the mechanism of recovery resistance to stem borer.
4. Faster tiller growth as a factor associated with tiller survival to stem borer depends on a number of interrelated factors:

   a. Presence of a genotype expressing this character.

   b. Physiological conditions of the plant (healthy or deadheart plant).

c. Temperature prevailing during the season of planting.

d. Feeding activity of the insect which may result in improving tiller growth.

Thirdly:

1. Under C. Partellus infestation, only part of the total number of tillers are productive.
2. Some tillers were attacked by the insect and the damage was in the form of deadheart and breakage (in juvenile tillers).
3. Part of the tillers died naturally. There is a seasonal effect on that.
4. Tillers can also be attacked by other insects such as shoot fly.

Fourthly:

1. The great potential for the expression of recovery resistance to stem borer in post-rainy season is mainly due to the effect of the prevailing low temperature in more tiller induction.
2. The effect of deadheart formation on grain yield in the lines is obscured by their compensatory ability due to the presence of recovery resistance.

General Conclusion:

Recovery resistance in sorghum to C. partellus can be considered as a function of multiple factors. Tillering capacity originally existed in the genetic make-up of the plants or the line, plant factors associated with tiller survival, viz. faster growth and rapid maturation of tillers, and environmental factors, namely temperature. In addition to that, a specific insect/host plant relationship operates in the direction of more tiller production and better growth.

REFERENCES

AICSIP (All India Coordinated Sorghum Improvement Project) 1975-1987. Progress Reports of the All India Coordinated Sorghum Improvement Project, Indian Council of Agricultural Research and Cooperative Agencies. New Delhi, India:AICSIP.

Alghali, A.M. 1985. Insect-host plant relationships. The spotted stalk-borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) and its principal host, sorghum. Insect Science and its Application 6:315-322.

Alghali, A.M. 1986. Effect of cultivar, time and amount of *Chilo partellus* Swinhoe (Lepidoptera: Pyralidae) infestation on sorghum yield components in Kenya. Tropical Pest Management 32(2):126-129.

Alghali, A.M. 1987. Effect of time of *Chilo partellus* Swinhoe (Lepidoptera: Pyralidae) infestation on yield loss and compensatory ability in sorghum cultivars. Tropical Agriculture 64(2):144-148.

Alghali, A.M., and Osisanya, E.O. 1984. Effect of damage by stalk-eyed fly (Diopsis thoracica) on yield components of rice. Experimental Agriculture 20: 225-234.

Ampofo, J.K.O. 1985. *Chilo partellus* (Swinhoe) oviposition on susceptible and resistant maize genotypes. Insect Science and its Application 6:323-330.

Ampofo, J.K.O. 1986. Effect of resistant maize cultivars on larval dispersal and establishment of *Chilo partellus* (Lepidoptera:Pyralidae). Insect Science and its Application 7:103-106.

Ampofo, J.K.O., and Saxena, K.N. 1989. Screening methodologies for maize resistant to *Chilo partellus* (Lepidoptera:Pyralidae). Pages 170-177 *in* Towards Insect Resistant Maize for the Third World: Proceedings of the International Symposium on methodologies for Developing Host Plant Resistance to Maize Insects, 9-14 March 1987, CIMMYT, Mexico: The International Maize and Wheat Improvement Center (CIMMYT).

Anonymous, 1970. SGB (The Sudan Gezira Board). Annual Agricultural Report, Season 1968/69. Barakat, Wadmedani, Sudan: SGB. 85 pp.

Anonymous, 1982. SGB (The Sudan Gezira Board). Annual Agricultural Report, Season 1981/82. Barakat, Wadmedani, Sudan: SGB. 90 pp.

Ayyangar, G.N.R. and Ponnaiya, B.W.X. 1939. Studies on Sorghum Sudanense, Stapf-the Sudan grass. Proceedings of the Indian Academy of Sciences 10: 237-254.

Baker, H.G. 1972. Human influences on plant evolution. Economic Botany. 26: 32-43.

Barry, D. 1971. Major cereals in Africa. Page 141 in 7th Annual Report. AID-ARS Project 1970.

Baur, J.R. 1979. Reduction of glyphosate-induced tillering in sorghum (Sorghum bicolor) by several chemicals Weed Science Journal 27(1): 69-73.

Beck, S.D.1965. Resistance of plants to insects. Annual Review of Entomology 10:207-232.

Beil, G.M. and Atkins, R.E. 1967. Estimates of general and specific combining ability in F1 hybrids for grain yield and its components in grain sorghum. Sorghum vulgare Pers. Crop Science 7: 225-228.

Bernays, E.A., Woodhead, S., and Haines, L. 1985. Climbing by newly hatched larvae of the spotted stalk borer *Chilo partellus* to the top of sorghum plants. Entomologia Experimentalis et Applicata 39:73-79.

Bernays, E.A., Chapman, R.F., and Woodhead, S. 1983. Behaviour of newly hatched larvae of *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) associated with their establishment in the host plant, sorghum. Bulletin of Entomological Research 73:75-83.

Blum, A. 1963. The penetration and development of the shoot fly in susceptible sorghum plants. Hassadel 44: 23-25 (in Hebrew).

Blum, A. 1968. Anatomical phenomena in seedlings of sorghum varieties resistant to sorghum shoot fly (Atherigona varia soccata). Crop Science 8:388-391.

Blum, A. 1969. Factors associated with tiller survival in sorghum varieties resistant to the sorghum shoot fly (Atherigona varia soccata). Crop Science 9:508-510.

Capinera, J.L. and Roltsch. W.J. 1980. Journal of Economic Entomology 73: 258-261.

Clegg, M.D. 1972. Light and yield related aspects of sroghum canopies. Pages 279-301 *in* Sorghum in the Seventies (Rao, N.G.P., and House, L.R., eds.). New Delhi, India: Oxford and IBH.

Dabarowski, Z.T. and Nyagiri, E.O. 1983. Some field and greenhouse experiments on maize resistance to *Chilo partellus* under western Kenya conditions. Insect Science and its Application 4:109-118.

Dabarowski, Z.T., and Kidiavai, E.L.1983. Resistance of some sorghum lines to the spotted stalk-borer *Chilo partellus* under western Kenya conditions. Insect Science and its Application 4(1-2):119-126.

Dahms, R.G.1972. The role of host plant resistance in integrated insect control. Pages 152-167 *in* Control of sorghum shoot fly (Jotwani, M.G., and Young, W.R., eds.). New Delhi, India: Oxford and IBH.

Dalvi, C.S., Dalaya, V.P.,and Khanvilkar, V.G. 1983. Screening of some sorghum varieties for resistance to stem borer, *Chilo partellus* (Swinhoe). Indian Journal of Entomology 45(3):266-274.

De Wet, J.M.J. and Shechter, Y. 1977. Evolutionary dynamics of sorghum domestication. Pages 179-191 *in* Crop resource (Siegler, D.S. ed.). New York, USA: Academic Press.

Doggett, H., Stark, K.J.,and Eberhart, S.A. 1970. Breeding for resistance to the sorghum shoot fly. Crop Science 10:528-531.

Doggett, H. 1972. Breeding for resistance to sorghum shoot fly in Uganda. *in* Control of sorghum shoot fly and screening for host plant resistance (Jotwani, M.G., and Young, W.R., eds.) New Delhi, India: Oxford and IBH.

Doggett, H. 1988. Sorghum. 2nd edn. Tropical Agricultural Series: Longman Scientific and Technical. 512 pp.

Downes, R.W. 1968. The effect of temperature on tillering of grain sorghum seedlings. Australian Journal of Agricultural Resarch 19:59-64.

Durbey, S.L., and Sarup, P. 1982. Morphlogical characters development and density of trichomeson varied maize germplasms in relation to preferential oviposition by the stalk borer, *Chilo partellus* (Swinhoe). Journal of Entomological Research 6:187-196.

Escalada, R.G. and Plucknett, D.L. 1975a. Ratoon cropping of sorghum: I. Origin, time of appearance, and fate of tillers. Agronomy Journal. 67: 473-478.

Escalada, R.G. and Plucknett, D.L. 1975b. Ratoon cropping of sorghum: II. Effect of day length and temperature on tillering and plant development. Agronomy Journal 67: 479-484.

Escalada, R.G. and Plucknett, D.L. 1977. Ratoon cropping of sorghum: III. Effect of nitrogen and cutting height on ratoon performance. Agronomy Journal 69: 341-346.

Evans, L.T., Wardlaw, I.F., and Williams, C.N. 1964. Environmental control of growth. Pages 102-125 in Grasses and grass lands (Barnard, C. ed.). London. UK: Macmillan.

Eveleens, K.G. 1983. Cotton-insect control in the Sudan Gezira: Analysis of a crisis. FAO Crop Protection 2:273-287.

FAO (Food and Agriculture Organization). 1991. Production FAO year book 1990. Volume 44, FAO Statistics Series No. 99, Rome, Italy: Food and Agriculture Organization.

Fischer, K.S., and Wilson, G.L. 1975. Studies on grain production in *Sorghum bicolor*(L.) Moench. V. Effect of planting density on growth and yield. Australian Journal of Agricultural Research 22:33-37.

Flattery, K.E. 1982. An assessment of pest damage of grain sorghum in Botswana. Experimental Agriculture 18(3):319-328.

Gahukar, R.T. and Jotwani, M.G. 1980. Present status of field pests of sorghum and millets in India. Tropical Pest management 26:138-151.

Gerik, T.J. and Neely, C.L. 1987. Plant density effects on main culm and tiller development of grain sorghum. Crop Science 27: 1225-1230.

Gramer, S.G. and Swanson, M.R. 1971. Detection of differences between means: A Monte Carlo study of five pairwise multiple comparison procedures. Journal of Agronomy 63:940-945.

Greathead, D. 1971. A review of biological control in Ethiopian region. CIBC Technical Communication no. 5. Farnham Royal, Slough, UK: Commonwealth Agricultural Bureaux. 162 pp.

Grimes, D.W., and Musick, J.T. 1960. Effect of spacing, fertility, and irrigation managements on grain sorghum production. Agronomy Journal 52:647-651.

Haensel, H.D., Ross, J.G., and Huang, C.C. 1963. Irradiation induced mutations in a colchicine reactive genotype in sorghum. Crop Science 10: 441-443.

Harlan, J.R. 1971. Agricultural origins: centers and non-centers. Science 174:468-474.

Harris, K.M. 1989. Recent advances in sorghum and pearl millet stem borer research. Pages 9-16 *in* the International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Harris, K.M. 1962. Lepidopterous stem borers of cereals in Nigeria. Bulletin of Entomological Research 53:139-171.

Harris, K.M. 1989. Bioecology of sorghum stem borers. Pages 63-71 *in* the International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

House, L.R. 1985. A guide to sorghum breeding. 2nd edn. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics. 206 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1991. Cereals Program Annual Report 1990. Patancheru, A.P. 502324, India: International Crops Research Istitute for the Semi-Arid Tropics. 138 pp.

ICRISAT (International Crops Research Istitute for the Semi-Arid Tropics). 1990. Annual Report 1989. Patancheru, A.P. 502324, India: International Crops Research Istitute for the Semi-Arid Tropics. 336 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1988. Annual Report 1987. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics. 390 pp.

Ingram, W.R. 1958. The lepidopterous stalk borers associated with Graminae in Uganda. Bulletin of Entomological Research 49: 367-383.

Ingram, W.R. 1983. Biological control of graminaceous stem-borers and legume pod-borers. Insect Science and its Application 4(1-2):205-209.

Jotwani, M.G., Chaudhari, S.,and Singh, S.P. 1978. Mechanism of resistance to *Chilo partellus* (Swinhoe) in sorghum. Indian Journal of Entomology 40:273-276.

Jotwani, M.G., Young, W.R., and Teetes, G.L. 1980. Elements of integrated control of sorghum pests. FAO Plant Production and Protection, paper 19. Rome, Italy; Food and Agriculture Organization. 159 pp.

Jotwani, M.G. 1982. Factors reducing sorghum yield: Insect pests. Pages 251-255 *in* Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Jotwani, M.G.1978. Investigations on insect pests of sorghum and millets with special reference to to host plant resistance: final technical report (1972-77). IARI Research Bulletin (New Series) no. 2. New Delhi, India: Indian Agricultural Research Institute. 116 pp.

Jotwani, M.G., Kundu, G.G., Kishore, P., Srivastava, K.P., Sukhani, T.R.and Singh, S.P.1979. Evaluation of some high yielding derivatives for resistance to stem borers, *Chilo partellus* (Swinhoe). Indian Journal of Entomology 41:1-4.

Jotwani, M.G., Srivastava, K.P.,and Kundu, G.G.1974. Two promising stem borer resistant lines of sorghum. Entomology Newsletter 4(9):51-52.

Jotwani,M.G., and Young, W.R. 1972. Recent developments on chemical control of insect pests of sorghum. Pages 377-398 *in* Sorghum in the Seventies (Rao, N.G.P., and House, L.R., eds.). New Delhi, India: Oxford and IBH.

Joyce, R.J.V. 1955. Cotton spraying in the Sudan Gezira. Entomological problems arising from spraying and spraying methods. FAO Plant Protection Bulletin 3:97-103.

Kalode, M.B., and Pant, N.C. 1967a. Effect of host plants on the survival, development, and behaviour of *Chilo partellus* (Swinhoe) under laboratory conditions. Indian Journal of Entomology 29:48-59.

Kambal, A.E. 1977. Progress and problems of sorghum research in the Sudan. Pages 475-518 *in* the International Sorghum Workshop 6-12 Mar 1977, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics. (limited distribution.)

Kambal, A.E. and Webster, O.J. 1966. Manifestation of hybrid vigor in grain sorghum and relation among the components of yield, weight per bushel, and height. Crop Science 6: 513-515.

Karchi, Z., and Rudich, Y. 1966. Effects of row width and seedling spacing on yield and its components in grain sorghum grown under dry land conditions. Agronomy Journal 58:602-604.

Karper, R.E. and Quinby, R.J. 1937. Hybrid vigor in sorghum. Journal of Heredity 28: 83-91.

Kausalya, K.G. 1989. Biophysical and anatomical factors associated with resistance in sorghum genotypes to sorghum stem borer, *Chilo partellus* Swinhoe. M.Sc. thesis, Andhra Pradesh Agricultural University, Rajendranagar, Hyderabad 500030, India. 142 pp.

Khurana, A.D. and Verma, A.N. 1982. Amino acid contents in sorghum plants, resistant/susceptible to stem borer and and shoot fly. Indian Journal of Entomology 44:184-188.

Khurana, A.D. and Verma, A.N. 1983. Some biochemical plant characters in relation to susceptibility of sorghum to stem borer and shoot fly. Indian Journal of Entomology 45:29-37.

Kishore, P. 1989. Chemical control of stem borers. Pages 73-79 *in* the International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Kogan, M. 1982. Plant resistance in pest management. Pages 93-134 *in* Introduction to insect pest management (Metcalf, R.L., and Luckman, W.H., eds.). 2nd edn. New York, USA: John Wiley and Sons. pp.

Kogan, M. and Paxton, J. 1983. Natural inducers of plant resistance to insects. Pages 144-171 *in* Plant resistance to insects (Comsock, M.J. ed.). American Chemical Society Symposium, Series 208, Washington, USA: ACS.

Kogan, M., and Ortman, E.F.1978. Antixenosis- A new term proposed to define Painter's "non-preference" modality of resistance. Bulletin of Entomological Society of America 24:175-176.

Kumar, K.,and and Bahatnagar, M.P. 1962. Studies on varietal resistance to sorghum stem borer (*Chilo zonellus* S.). Indian Journal of Agricultural Sciences 32:208-218.

Kundu, G.G., and Jotwani, M.G.1977. 447 and VZM-2B - Two promising stem borer derivatives of sorghum. Sorghum Newsletter 20:59.

Lal, G. and Pant, J.C. 1980 b. Laboratory and field testing for resistance in maize and sorghum varieties to *Chilo partellus*(Swinhoe). Indian Journal of Entomology 42:606-610.

Lal, G.and Pant, J.C. 1980 a. Ovipositional behaviour of *Chilo partellus* (Swinhoe) on different resistant and susceptible varieties of maize and sorghum. Indian Journal of Entomology 42(4):772-775.

Leppic, E.E. 1970. Gene centers of plants as sources of disease resistance. Annual Review of Phytopathology 8:324-344.

Leüschner, K. 1989. A review of sorghum stem borer screening procedures. Pages 129-135 *in* the International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Luginbill, P., Jr. 1969. Developing resistant plants- the ideal method of controlling insects. Rsearch Report no. 111. Washington, D.C., USA: United States Department of Agriculture. 14 pp.

Major, D.J., Hamman, W.M., and Rood, S.B. 1982. Effect of short duration chilling temperature exposture on growth and development of sorghum. Field Crops Research 5: 129-136.

Mengesha, M.H., and Parasada Rao, K.E. 1982. Current situation and future of sorghum germplasm. Pages 323-333 *in* Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Metcalf, R.L. 1986. The ecology of insecticides and the chemical control of insects. Pages 251-297 *in* Ecological theory and integrated pest management practice (Kogan, M., ed.). New York, USA: John Wiley and Sons.

Mihm, J.A., Peairs, F.B., and Ortega, A. 1978. New procedures for efficient mass production and artificial infestation with lepidopterous pests of maize. CIMMYT Review, Mexico: Centro Internacional de Mejoramiento de Maiz y Trigo. 138 pp.

Milthorpe, F. and Davidson, J. 1966. Physiological aspects of regrowth in grasses. Pages 241-255 *in* The growth of cereals and grasses (Milthorpe, F.L. and Ivius. J.D. eds.). Easter School in Agricultural Science. University of Nottingham, UK.

Mitchell, R.L. 1970. Crop growth and culture. Ames. Lowa, USA: Lowa State University Press. 349 pp.

Mote, U.N., Kadam, J.R. and Bapat, D.R. 1985. Recovery resistance to shoot fly in some sorghum hybrids. Journal of Maharashtra Agricultural University 10:190-193.

Myers, R.J.K., Foale, M.A., and Keefer. G.D. 1986. Sorghum growth and development in three tropical and subtropical environment 1. Phasic development tillering and leaf production. Pages 4.43-4.54 in Proceedings of the First Australian Sorghum Conference. 4-6 Feb. 1986 Gatton Queensland. Australia. Queensland 4067 Ausgralia: CSIRO Division of Tropical Crops and Pastures.

Narwal, R.P. 1973. Silica bodies and resistance to infection in jowar (*Sorghum vulgare* Pers.). Agra University journal of Research (Science) 22:17-20

Nasr Eldin, N.M., 1965. Studies on some aspects of the biology, ecology, and control of dura stalk borer *Chilo partellus* (Swinhoe) (Lepidoptera:Pyralidae) in the Sudan. M.Sc thesis, Faculty of Agriculture, Shambat, University of Khartoum, Sudan.84 pp.

Nwanze, K.F. and Mueller, R.A.E. 1989. Management options for sorghum stem borers for farmers in the semi-arid tropics. Pages 105-114 *in* the International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Nwanze, K.F., Reddy, Y.V.R., Taneja, S.L., Sharma, H.C., and Agrawal, B.L. 1991. Evaluating sorghum genotypes for multiple insect resistance. Insect Science and its Application 21(1,2,3):183-188.

Nwanze, K.F., and Reddy, Y.V.R. 1991. A rapid method for screening sorghum for resistance to *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae). Journal of Agricultural Entomology 8(1):41-49.

Nye, I.W.B. 1960. The insect pests of Graminaceous crops in East Africa. Colons Research Study 31. Colons Office, London. UK, 47 pp.

Omori, T., Agrawal, B.L., and House, L.R. 1988. Genetic divergence for resistance to shoot fly, *Atherigona soccata* Rond. in sorghum, *Sorghum bicolor* (L.) Moench, and its relationship with heterosis. Insect Science and its Application 9(4):483-488.

Painter, R.H. 1951. Insect resistance in crop plants. New York, USA: Macmillan. 520 pp.

Painter, R.H.1958. Resistance of plants to insects. Annual Review of Entomology 3:267-290.

Pant, N.C., Pathak, M.D., and Pant, J.C.1961. Resistance to *Chilo partellus* (Swin.) in different host plants. 1. Development of the larvae on different hosts. Indian Journal of Entomology 23:128-136.

Peacock, J.M. and Wilson, G.L. 1984. Sorghum. Pages 249-279 *in* the Physiology of tropical field crops (Goldsworth, P.R. and Fisher, N.M. eds.): John Wiley and Sons Ltd.

Phillips, I.D.J. 1975. Apical dominance. Annual Review of Plant physiology 26:341-367.

Pickett, R.C., and Fredericks, E.E. 1959. The new look in sorghum Report of Purdue University agricultural experimental station 2:5-8.

Plucknett, D.L., Escalada, R.G., and De La Pena, R.S. 1984. Crop ratooning. Pages 151-175 *in* Crop physiology: Advancing frontiers (U.S. Gupta ed.). New Delhi, India: Oxford and IBH.

Prabhakar, and Goud, J.V. 1987. Inheritance of tillering. Stem girth, and anther colour in translocation stocks XJ. Set-3 sorghum crosses. Sabrao Journal 19(1): 17-25.

Pradhan, S.1971. Investigations on insect pests of sorghum and millets. Final Technical Report (1965-1970), Division of Entomology, Indian Agricultural Research Institute, New Delhi, India. 157 pp.

Quinby, J.R. 1962. Manifestation of hybrid vigor in sorghum. Crop Science 3: 288-291.

Quinby, J.R., Hesketh, J.D., and Voigt, R.L. 1973. Influence of temperature and photoperiod of floral initiation and leaf number in sorghum. Crop Science 13: 243-246.

Rahman, K.A., 1944. Biology and control of maize and jowar borer (*Chilo partellus* Swinh.). Indian Journal of Agricultural Sciences 14:303-307.

Rao, V.M. 1964. Survey of natural enemies of pests of paddy. Final report P-480 Project no. A 7-ENT-5. Bangalore, Karnataka, India: Commonwealth Institute of Biological Control.

Reddy, K.V.S., and Davies, J.C. 1979. Pests of sorghum and pearl millet and their parasites and predators recorded at ICRISAT Center up to Augest, 1979. Cereal Entomology Progress Report 2. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics. (Restricted distribution.)

Roome, R.E., Chadha, G.K., and Padgham, D. 1977. Choice of oviposition site by *Chilo*, the sorghum stem borer. Bulletin SROP 3:115-121.

Russell, G.E.1978. Plant breeding for pest and disease resistance. London, UK: Butterworth and Co. 485 pp.

Schulze, L.D. 1971. Effect of plant population in tillering. M.Sc. Thesis. University of Nebraska, USA.

Seshu Reddy, K.V. 1985. Integrated approach to the control of sorghum stem borers. Pages 205-215 *in* proceedings of the International Sorghum Entomology Workshop, 15-21 Jul 1984, college station, Texas, USA. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Seshu Reddy, K.V. 1989. Sorghum stem borers in eastern Africa. Pages 33-40 *in* the International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Seshu Reddy, K.V. 1989. Sorghum stem borers in eastern Africa. Pages 33-40 *in* the International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Seshu Reddy, K.V. and Davies, J.C. 1979. A new medium for mass rearing of sorghum stem borer, Chilo partellus Swinhoe (Lepidoptera: Pyralidae) and its use in resistance screening. Indian Journal of Plant Protection 6:48-55.

Seshu Reddy, K.V. 1969. Biology of the stem borer *Chilo zonellus* S. on hybrid jowar (CSH-1) *Sorghum vulgare* Pers. Andhra Agricultural Journal 16:131-136.

Seshu Reddy, K.V. 1983. Studies on stem borer complex of sorghum in Kenya. Insect Science and its Application 4(1-2):3-10.

Shamsuddin, A.M. 1967. Photoperiodic effects of primary and ratoon growth in three varieties of grain sorghum. Dissertation Abstract 28: 22318.

Sharma, A.K., Saxena, J.D., and Rao, B.R.S. 1966. A catalog of the hymenopterous and dipterous parasites of *Chilo zonellus* (swinhoe) (Crambidae: Lepidoptera). Indian Journal of Entomology 28:510-542.

Sharma, G.C., Jotwani, M.G., Rana, B.S. and Rao, N.G.P. 1977. Resistance to the sorghum shoot fly, *Atherigona soccata* (Rondani) and its genetic analysis. Journal of Entomological Research 1(1):1-12.

Sharma, H.C. 1985. Screening for sorghum midge resistance and resistance mechanisms. Pages 275-292 *in* Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, college station, Texas, USA. Patancheru, A.P. 502324, India: Internatinal Crops Research Institute for the Semi-Arid Tropics.

Sharma, H.C., Taneja, S.L.,and Leüschner, K. 1983. Screening sorghums for resistance to insect pests. Presented at the All India Coordinated Sorghum Improvement Project Workshop, 18-21 Apr 1983, Haryana Agricultural University, Hisar, India. Patancheru, A.P., 502324, India: International Crops Research Institute for the Semi-Arid Tropics. (Limited distribution.)

Sharma, V.K., and Sarup,P.1979. Predatory role of spiders in the integrated control of maize stalk borer, *Chilo partellus* Swinhoe. Journal of Entomological Research 3:229-231.

Sharma, V.K.,and Chatterji, S.M. 1971a. Preferential oviposition and antibiosis in different maize germplasms against *Chilo zonellus* (Swin.) under cage conditions. Indian Journal of Entomology 33:299-311.

Siddig, S.A. 1972. Graminaceous stem borers in the northern province of the Sudan. 1. Ecological Studies. Zeit schrift fuer Angewandte Entomologie 71:376-381.

Singh, B.U., and Rana, B.S. 1984. Influence of varietal resistance on ovipositional and larval development of stalk-borer *Chilo partellus* Swin., and its relationship to field resistance in sorghum. Insect Science and its Application 5:287-296.

Singh, B.U., Rana, B.S., Reddy, B.B.,and Rao, N.G.P. 1983. Host plant resistance to stalk borer, *Chilo partellus* Swin., in sorghum. Insect Science and its Application 4(4):407-413.

Singh, R.K., and Chaudhary, B.D. 1977. Classificatory analysis. Pages 195-223 *in* Biometrical methods in quantitative genetic analysis. New Delhi, India: Kalyani Publisher.

Singh, S.R., Vedamoorty, G., Thobbi, V.V., Jotwani, M.G., Young,W.R., Balan, J.S., Srivastava, K.P., Sandhu, G.S., and Krishnananda, N. 1968. Resistance to stem borer *Chilo zonellus* (Swinhoe) and *Atherigona varia soccata* Rond. in world sorghum collection in India. Memoirs of Entomological Society of India 7:1-79.

Singh, S.P., Jotwani, M.G., and Rana, B.S. 1980. Development and stability of sorghum varieties resistant to stem borer, *Chilo partellus* (Swinhoe). Indian Journal of Entomology 42(3):473-481.

Sinha, S.K.,and Parasad, S.M.1975. A biological approach to the control of the maize stalk borer, *Chilo zonellus* Swinhoe. Current Science 44:197-198.

Skoroszewski, R.W., and van Hamburg, H. 1987. The release of *Apanteles flavipes* (Cameron) (Hymenoptera: Braconidae) against stalk borers of maize and grain sorghum in South Africa. Journal of the Entomological Society of of Southern Africa 50(1):249-255.

Smith, C.M. 1989. Plant resistance to insects: A fundamental approach . New York, USA: John Wiley and Sons. 286 pp.

Starks, K.J. 1970. Increasing infestation of the sorghum shootfly in experimental plots. Journal of Economic Entomology 63:1715.

Starks, K.J., Eberhart, S.A., and Doggett, H. 1970. Recovery from shoot fly attack in a sorghum diallel. Crop Science 10:519-522.

Stickler, F.C., and Laude, H.H. 1960. Effect of row spacing and plant population on performance of corn, grain sorghum and forage sorghum. Agronomy Journal 52:275-277.

Stickler, F.C., and Wearden, S. 1965. Yield and yield components of grain sorghum as affected by row width and stand density. Agronomy Journal 57:564-567.

Swaine, G., and Wyatt, C.A. 1954. Observations on the sorghum shoot fly. East Africa Agricultural Forestry Journal 20: 45-48.

Swarup, V.and Chaugale, D.S.1962. A preliminary study on resistance to stem borer *(Chilo zonellus* Swinh.) infestation on sorghum *(Sorghum vulgare* Pers.). Current Science 31:163-164.

Taneja, S.L. 1987. Host-plant resistance in the management of sorghum stem borer. Pages 212-233 *in* Recent advances in entomology (Mathur, Y.K. eds.). Gopal Prakashan, Kanpur: India.

Taneja, S.L., and Woodhead, S. 1989. Mechanisms of stem borer resistance in sorghum. Pages 137-143 *in* the International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Taneja, S.L., and Nwanze, K.F. 1988. Mass production of spotted stem borer, Chilo partellus Swinhoe on artificial diet. Pages 77-92 *in* Biocontrol technology for sugar cane pest management (David, H. and Easwara Moorthy, S. eds.). Coimbatore 641007, Tamil Nadu, India: Sugar cane breeding Institute (ICAR).

Taneja, S.L. and Nwanze, K.F. 1989. Assessment of yield loss of sorghum and pearl millet due to stem borer damage. Pages 95-104 *in* the International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Taneja, S.L., and Leüschner, K. 1985. Methods of rearing, infestation, and evaluation for *Chilo partellus* resistance in sorghum. Pages *in* proceedings of the International Sorghum Entomology Workshop, 15-21 Jul 1984, College station Texas, USA. Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Teetes, G.L., Seshu Reddy, K.V., Leüschner, K. and House, L.R. 1983. Sorghum insects identification handbook. Information Bulletin No. 12. ICRISAT, Patancheru, A.P. 502324, India: International Crops Research Institute for the Semi-Arid Tropics.

Trehan, K.N. and Butani, D.K. 1949. Notes on the life history, binomics, and control of *Chilo zonellus* (Swinhoe) in Bombay province. Indian Journal of Entomology 11:47-59.

Van Rensburg, N.J., and van hamburg, H. 1975.Grain sorghum pests: an integrated control approach. Pages 151-162 *in* proceedings of the First Congress of the Entomological Society of Southern Africa, 30 Sep-3 Oct 1974, Stellenboch, South Africa (Durr, H.J.R., and Neser, S., eds.). Pretoria, South Africa: Entomological Society of Southern Africa.

Vanderlip, R.L. 1979. How a sorghum plant develop. Contribution No. 1203, Agronomy department, Kansas Agricultural Experiment station, Manhattan, 66506, USA. 19 pp.

Vidyabhushanam, R.V., 1972. Breeding for shoot fly resistance in India. Pages 218-232 in Control of Sorghum Shoot fly (Jotwani, M.G., and Young, W.R., eds.). New Delhi. India: Oxford and IBH.

Warrington, I.J., Edge, E.A. and Green, L.M. 1978. Plant growth under high radient energy fluxes. Annual Botany 42: 1305-1313.

Webster, O.J. 1965. Genetic studies on *Sorghum vulgare* Pers. Crop Science 5: 207-210.

Williams, T.E. 1966. Root activity of perennial grass swards. Pages 270-279 in Root growth (Whittington. W.J. ed.). New York, USA: Plenum Press.

Wilson, G.L. and Eastin, J.D. 1982. The plant and its environment. Pages 101-119 *in* Sorghum in the Eightiees: Proceedings of the of the International Symposium on Sorghum, 2-7 Nov 1981, ICRISAT Center, India, Patancheru, A.P., 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Wiseman, B.R., Davies, F.M., and Campell, J.E. 1980. Mechanical infestation device used in fall armyworm plant resistance program. Florida Entomologist 63:425-432.

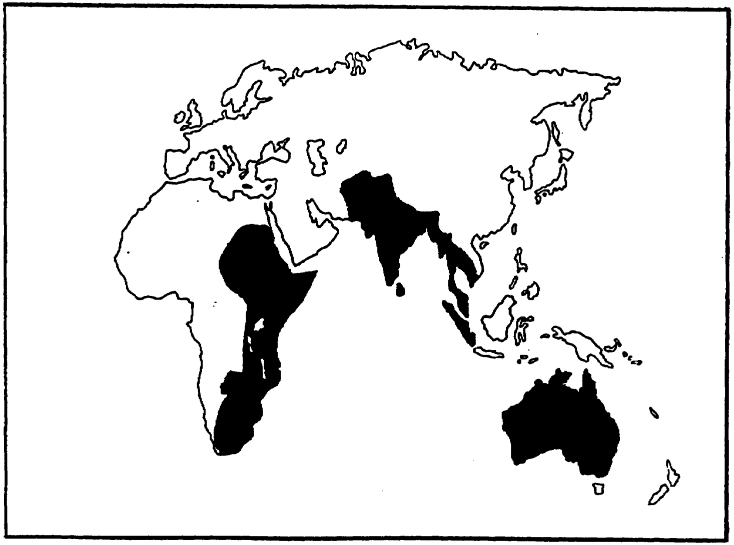
Woodhead, S., Bernays, E.A., and Chapman, R.F. 1983. Report on visit to ICRISAT in 1981 and 1982. COPR/ICRISAT Collaborative Project on the Sorghum stem borer. COPR, London, U.K. 42 pp.

Woodhead, S., and Taneja, S.L. 1987. The importance of the behavior of young larvae in sorghum resistance to *Chilo partellus*. Entomologia Experimentalis et Applicata 45:47-54.

Young, W.R., and Teetes, G.L. 1977. Sorghum entomology. Annual Review of Entomology 22:193-218.

APPENDICES

APPENDIX A



World distribution of _C. partellus_ (source: Ampofo and Saxena, 1989)

APPENDIX B

Total area, yield and production of the four major cereal crops in the Sudan 1979-1990 (source: FAO Year Book, 1991).

	Area harvested (1000 ha)				Yield (Kg ha^{-1})				Production (1000 MT)			
Crop	1979-81	1988	1989	1990	1979-81	1980	1989	1990	1979-81	1988	1989	1990
Sorghum	3163	5983*	3801	2925*	731	752	404	514	2361	4425*	1536	1502*
Millet	1094	2320*	1559*	1150F	418	213	104	77	456	495	162	112*
Wheat	285	144	197	258	907	1236	1240	1586	206	191	247	409
Maize	67	40*	35F	50F	582	750	714	700	39	30F	25F	35F

* = Unofficial figure

F = FAO estimate

APPENDIX C

The selected eight lines from glasshouse studies with description of 14 descriptors numbers (source:GRU, ICRISAT).

Descriptor	Entries							
	IS 3492	IS 9751	IS 19474	IS 19624	IS 19652	IS 22498	IS 22806	IS 25041
1. Pedigree	Fetereita Shendi	DS 8	VAR-LOPE	CROSS-67/70	CROSS-36:1	-	-	-
2. Location	Tozi	GRS	-	-	-	-	-	-
3. Original entry No.	423	-	-	-	-	A-69-S	S-7	AB-62
4. 50% flowering (rabi)	54	55	79	76	65	57	77	72
5. 50% flowering (kharif)	54	52	80	68	64	60	81	74
6. Basal tillering	3	3	3	3	4	3	3	2
7. Nodule tillering	P	P	P	P	P	P	P	A
8. Plant height cm (rabi)	205	170	180	110	120	135	255	195
9. Plant height cm (kharif)	245	250	360	145	160	210	330	360
10. Grain colour	CW	G	G	W	W	B	G	LR
11. Grain size (mm)	4.0	4.0	2.5	2.8	2.8	2.5	2.0	3.5
12. Threshability	PT	FT	FT	FT	FT	-	FT	FT
13. 1000 seed weight (gm)	4.72	4.77	2.32	3.40	4.76	2.73	2.45	3.76
14. Classification	C	C	C	C	C	C	C	D

A = Absent, B = Brown, C = Caudatum, D = Durra, G = Gray, CW = Chalky white, LR = Light red, P = Present, W = White.

APPENDIX D

APPENDIX D1. Ingredients of artificial diet used for mass rearing of sorghum stem borer *C. partellus* at ICRISAT Center (source: Taneja and Nwanze, 1988).

Ingredient	Quantity
Fraction 'A'	
Water	2000 ml
Kabuli gram flour**	438.4 g
Brewer's Yeast	32.0 g
Sorbic acid	4.0 g
Vitamin 'E' (Viteolin capsules)	4.6 g
Methyl parahydroxy benzoate	6.4 g
Ascorbic acid	10.4 g
Sorghum leaf powder	160.0 g
Fraction 'B'	
Agar-Agar	40.8 g
Water	1600 ml
Formaldehyde (40%)	3.2 g

* The quantities used to prepare 15 jars of 300 g diet each

** Kabuli gram is a cultivar of Chickpea (Cicer arietinum)

Contd..

Contd..

APPENDIX D2. Tables 1 and 2. Minimum temperature recorded during taking observation on tiller appearance.

Table 1. Post-rainy season, 1990/91

Date	19-20/1 1991	21-22	23-24	25-26	27-28	29-30	31/1-1/8	2-3/8	4-5/8	6-7/8	8-9/8	10-11/8 1991
DAE	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	36-37	38-39
Temperature C°	17.5	18.0	17.3	16.0	12.3	12.2	13.6	13.4	11.5	17.3	16.6	18.0

Mean= 15.3

Table 2. Rainy season, 1991

Date	29-30/6 1991	1-2/7	3-4	5-6	7-8	9-10	11-12	13-14	15-16	17-18	19-20	21-22	23-24	25-26	27-28	29-30	31/7-1/8	2-3/8	4-5/8 1991
DAE	9-10	11-12	13-14	15-16	17-18	19-20	21-22	23-24	25-26	27-28	29-30	31-32	33-34	35-36	37-38	39-40	41-42	43-44	45-46
Tempe-rature C°	22.5	22.5	22.8	21.7	22.0	21.8	22.5	22.0	22.5	22.9	22.5	22.3	22.8	23.0	22.9	23.0	22.3	22.3	23.0

Mean=22.5

Each figure of temperature represent mean of the two corresponding days.

DAE = Days after crop emergence.

APPENDIX E

Results of initial screening of the germplasm accessions under *C. partellus* artificial infestation.

S. No.	IS No.	TDH %	SBDH %	SFDH %	RS
1	9751	98	50	48	2
2	22806	94	61	33	2
3	9761	98	53	45	2
4	9687	100	59	41	2
5	19474	100	59	41	2
6	22864	94	47	47	3
7	9829	93	38	55	3
8	9837	98	58	40	3
9	9838	97	43	54	3
10	9762	88	56	32	3
11	22563	100	51	49	3
12	9653	100	51	49	3
13	22361	100	54	46	3
14	9749	100	55	45	3
15	3492	98	53	45	3
16	6974	97	52	45	3
17	3585	95	60	35	4
18	22498	95	55	40	4
19	19624	98	58	40	4
20	22511	92	65	27	4
21	22407	77	49	28	4
22	22360	97	53	44	4
23	20500	97	49	49	4
24	22555	97	54	43	4
25	2305	100	62	39	4
26	19652	100	55	45	4
27	940	93	45	48	4
28	7051	93	68	25	4
29	9284	97	29	68	4
30	9649	94	50	44	4
31	22523	100	57	43	4
32	9884	95	50	45	4
33	25041	93	43	50	4
34	19304	93	48	45	4
35	19598	91	50	41	4
36	21760	95	55	39	4
37	939	92	51	41	5
38	20515	90	48	42	5
39	3605	93	50	43	5
40	2303	100	52	48	5
41	9983	84	43	41	5
42	19653	95	56	39	5
43	19098	100	54	46	5

Contd..

(Contd...)

S. No.	IS No.	TDH %	SBDH %	SFDH %	RS
44	22404	81	46	35	5
45	19203	86	55	31	5
46	19228	89	49	40	5
47	2309	95	51	44	5
48	2314	94	53	41	5
49	7068	100	55	45	5
50	22405	91	49	43	5
51	9815	80	41	38	5
52	25036	93	50	43	5
53	19646	95	50	45	5
54	950	95	68	27	5
55	3505	81	49	32	5
56	19642	89	46	43	5
57	3496	92	51	41	5
58	6906	98	40	58	5
59	22532	81	49	32	5
60	19308	97	54	43	5
61	12725	85	40	45	5
62	24981	90	48	42	5
63	6994	96	44	52	5
64	3604	88	38	50	5
65	9670	75	40	35	5
66	20511	93	47	47	5
67	3566	85	41	44	5
68	19287	93	55	38	5
69	3491	93	55	38	5
70	25044	87	43	43	5
71	22414	85	49	36	5
72	9648	93	50	43	5
73	3530	87	52	35	5
74	23387	89	56	33	5
75	22408	90	53	37	5
76	9660	88	55	33	5
77	19153	81	42	39	5
78	22481	82	46	36	5
79	52033	89	52	37	5
80	19013	90	45	45	5
81	1398	87	48	39	5
82	9742	86	52	34	5
83	2311	97	41	56	5
84	22541	95	52	43	5
85	14481	86	44	42	5
86	9685	85	44	41	5

Contd..

S. No.	IS No.	TDH %	SBDH %	SFDH %	RS
87	2310	92	54	38	5
88	9982	90	52	38	5
89	22457	85	47	48	5
90	23021	92	52	40	5
91	22830	90	50	40	5
92	2489	88	63	25	5
93	21784	85	46	39	5
94	19072	83	45	38	5
95	19078	80	32	48	5
96	9847	87	59	28	5
97	19644	92	50	42	5
98	1324	83	45	38	5
99	23003	93	50	43	5
100	24977	89	49	40	5
101	20585	80	50	30	6
102	22530	93	50	43	6
103	22534	93	50	43	6
104	19473	88	47	41	6
105	8786	90	57	33	6
106	22409	88	44	44	6
107	25038	84	47	37	6
108	22499	84	52	32	6
109	22359	93	68	25	6
110	22571	95	65	30	6
111	19473	94	60	34	6
112	22376	80	40	40	6
113	22504	86	52	34	6
114	8689	82	38	44	6
115	19138	83	41	42	6
116	22364	88	52	36	6
117	9764	75	45	30	6
118	19600	85	49	36	6
119	2291	88	53	35	6
120	929	34	14	20	6
121	21772	97	52	45	6
122	19361	83	50	33	6
123	19366	89	48	41	6
124	9758	83	50	33	6
125	19234	90	50	40	6
126	8701	86	43	43	6
127	23386	83	45	38	6
128	19198	93	56	37	6
129	22575	81	43	38	6
130	22578	79	41	38	6
131	19586	74	49	27	6
132	9651	86	34	52	6
133	19592	83	35	48	6
134	20589	81	40	41	6

Contd..

(Contd..)

S. No.	IS No.	TDH %	SBDH %	SFDH %	RS
135	2265	89	51	38	6
136	19360	82	38	44	6
137	19608	93	47	46	6
138	19615	85	50	35	6
139	22367	90	52	38	6
140	8688	87	67	20	6
141	10070	77	35	42	6
142	2262	80	44	36	6
143	22519	77	46	31	6
144	22520	95	52	43	6
145	2293	80	42	38	6
146	21797	91	55	36	6
147	19012	79	34	45	6
148	21821	84	45	39	6
149	9813	78	43	35	6
150	20582	80	52	28	6
151	19654	84	45	39	6
152	2339	100	53	47	6
153	2344	80	32	48	6
154	21780	88	50	38	6
155	21796	81	39	42	6
156	21768	79	45	34	6
157	21822	82	46	36	6
158	9644	95	70	25	6
159	21791	82	45	37	6
160	22521	100	59	41	6
161	19140	90	58	32	6
162	19142	72	47	25	6
163	21790	86	43	43	6
164	8796	88	53	35	6
165	21779	83	42	41	6
166	25032	84	45	39	6
167	9652	80	35	45	6
168	22533	77	44	33	6
169	24978	87	54	33	6
170	22387	88	50	38	6
171	23009	84	47	37	6
172	22547	87	55	32	6
173	20518	87	50	37	6
174	22369	75	39	36	6
175	19512	88	50	38	6
176	23389	81	40	41	6
177	19058	86	41	45	6
178	22543	80	44	36	6
179	21806	86	52	34	6
180	19627	90	45	45	6
181	22368	77	39	38	6
182	6953	90	52	38	7

Contd..

S. No.	IS No.	TDH %	SBDH %	SFDH %	RS
183	921	100	48	52	7
184	19622	76	39	37	7
185	2471	83	45	38	7
186	9684	83	49	34	7
187	923	30	10	20	7
188	3584	79	46	33	7
189	19573	87	40	47	7
190	24980	75	37	38	7
191	925	40	15	25	7
192	7071	81	48	33	7
193	926	90	39	51	7
194	9625	85	50	35	7
195	9668	83	40	43	7
196	7070	89	58	31	7
197	6972	88	59	29	7
198	932	30	15	15	7
199	21767	86	43	43	7
200	19632	79	47	32	7
201	9647	81	40	41	7
202	949	86	54	32	7
203	24991	73	41	32	7
204	19588	84	52	32	7
205	19647	84	52	32	7
206	22959	79	41	38	7
207	21773	92	56	36	7
208	21771	100	61	39	7
209	2903	96	72	24	7
210	9250	100	77	23	7
211	24997	78	43	35	7
212	9286	84	52	32	7
213	25027	84	46	38	7
214	9227	83	45	38	7
215	19574	97	67	30	8
216	22406	84	42	42	8
217	19631	90	48	42	8
218	25002	77	45	32	8
219	19150	75	42	30	8
220	19636	83	42	41	8
221	25031	74	46	28	8
222	21759	80	47	33	8
223	19131	100	48	52	8
224	21782	84	44	40	8
225	21783	89	45	44	8
226	25004	78	40	38	8
227	22573	81	46	35	8
228	19569	83	49	34	8

Contd..

S. No.	IS No.	TDH %	SBDH %	SFDH %	RS
	ICSV 700	57	25	32	7
	IS 2205	58	25	33	7
	IS 1044	54	28	26	5
	IS 2146	57	27	30	7
	CSH 1	96	38	58	5
	CSH 5	89	46	43	6
	ICSV 1	87	19	86	6
	ICSV 112	84	48	36	5

IS = International Sorghum
TDH% = Total deadheart percentage
SBDH% = Percentage stem borer deadheart
SFDH% = Percentage shoot fly deadheart
RS = Recovery score

Note: Lines from S.No. 1-48 were selected for glasshouse studies.

APPENDIX F

Between and within clusters analysis of variance for recovery resistance parameters - glasshouse screening: First planting

SV	d.f	SS			MS			VR		
		% Recovered plants	Tiller survival (%)	Recovery score	% Recovered plants	Tiller survival (%)	Recovery score	% Recovered plants	Tiller survival (%)	Recovery score
Replication	4	4335.9	302.2	15.8	1084.0	75.5	3.9			
Genotypes	36	81660.0	23399.5	798.8	2268.3	650.0	22.2	3.0**	4.5**	7.9**
Clusters	10[1]	72890.1	21074.1	730.7	2289.0	2107.4	73.1	3.0**	14.6**	26.1**
Genotypes/ Clusters	26[2]	8769.9	2323.4	68.1	337.3	89.4	2.6	0.4NS	0.6NS	0.9NS
Error	144	110008.8	207.1	396.6	763.9	143.8	2.8			

1. Resulted from number of clusters which is 11.
2. Resulted from summation of degrees of freedom of genotypes within the clusters.
** = Significant at 1% level, NS=Not significant.

APPENDIX G

Correlation coefficients of a number of characters studied in post-rainy season.

Characters		Characters	r-value
DH% T_2 (MS)	VS	MS height	0.11^{NS}
DH% T_3 (MS)	VS	MS height	0.07^{NS}
DH% T_2 (MS)	VS	Boot stage	-0.21^{NS}
DH% T_3 (MS)	VS	Boot stage	-0.42^{*}
DH% T_2 (MS)	VS	Angle of tiller	0.42^{*}
DH% T_3 (MS)	VS	Angle of tiller	0.42^{*}
Total No. of tillers (T_1)	VS	Angle of tiller	0.62^{**}
Total No. of tillers (T_1)	VS	% contribution of tillers in grain yield (T_1)	0.73^{*}
Total No. of tillers (T_1)	VS	% contribution of tillers in grain yield (T_2)	0.33^{NS}
Total No. of tillers (T_1)	VS	% contribution of tillers grain yield (T_3)	0.36^{NS}
Total No. of tillers (T_1)	VS	% tillers breakage	-0.92^{**}
Angle of tiller	VS	% tillers breakage	0.81^{**}
DH% in tillers (14 day-old)	VS	Tiller height (14 day-old)	-0.49^{*}
DH% in tillers (21 day-old)	VS	Tiller height (21 day-old)	-0.02^{NS}
DH% in tillers (28 day-old)	VS	Tiller height (28 day-old)	-0.10^{NS}
DH% in tillers (14 day-old)	VS	Boot stage	0.13^{NS}
DH% in tillers (21 day-old)	VS	Boot stage	0.41^{*} (1)
DH% in tillers (28 day-old)	VS	Boot stage	0.51^{*} (2)
% Natural tiller mortality (T_1)	VS	% contribution of tillers in total grain yield (T_1)	-0.80^{**}
DH% T_2 (MS)	VS	% Reduction in grain yield	0.01^{NS}
DH% T_3 (MS)	VS	% Reduction in grain yield	0.01^{NS}
DH% ($\bar{X}$) (MS)	VS	% Reduction in grain yield	0.11^{NS}

MS=Main Stem, DH= Deadheart, T1= Control, T2= MS infestation, and T3= MS + tiller infestation treatment.

(1) $r=0.46^{*}$ after excluding the line IS 25041,

(2) $r=0.55^{**}$ after excluding the line IS 25041.

($\bar{X}$) = Mean of T2 and T3.

**= Significant at 1%, *= Significant at 5% level, and NS=not significant.

APPENDIX H

Table H1. Result of comparison between deadherat formation in the main stem, and main stem + tiller infestation treatments : Post-rainy season.

	X-Y	T-value	Probability
	-2.0833	-1.1550	0.2604^{NS}

X- Deadheart in main stem infestation treatment
Y- Deadheart in main stem + tiller infestation treatment

Table H2. Result of comparison between deadheart formation and leaf feeding in tillers of the three age groups.

1. Leaf feeding	X-Y	T-value	Probability
14 vs 21	0.2500	1.3656	0.1858^{NS}
21 vs 28	0.8333	2.6320	0.1522*
14 vs 28	1.0833	3.4063	0.0025**
2. Deadheart			
14 vs 21	25.8333	7.0635	0.0000**
21 vs 28	3.7500	1.7404	0.0957^{NS}
14 vs 28	29.5833	7.9229	0.0000**

14= 14 day-old tiller
21= 21 day-old tiller
28= 28 day-old tiller
**= Significant at 1%, *= Significant at 5% level,and NS=not significant.

APPENDIX I

Total number of basal tillers produced in the control and infestation treatments : Postrainy season.

	Treatments (tillers/20 plants)			
Sorghum line	T1	T2	T3	Mean
IS 3492	95.7	156.7	149.0	133.8
IS 9751	77.7	149.7	133.7	120.3
IS 19474	58.7	83.7	102.3	81.6
IS 19624	28.7	76.3	86.0	63.7
IS 19652	50.3	96.3	101.3	82.7
IS 22498	47.7	90.3	111.0	79.7
IS 22806	55.7	76.3	95.7	75.9
IS 25041	81.3	138.3	143.3	121.0
Mean	62.0	107.2	115.3	94.8

	SE(+)	CV(%)	LSD 0.05
For comparing treatments	2.2***	3.9	8.6
For comparing genotypes	3.3***	10.4	9.4
For comparing treat. x Gen. (within same level of treat.)	5.68**	10.4	16.2
For comparing treat. x Gen. (accross treatments)	5.73**	10.4	16.4

T1 = Control treatment, T2 = Main stem infestation,
T3 = Main stem with tiller infestation.
*****=Significant at 0.1%, **= Significant at 1% .**

APPENDIX J

Tiller appearance pattern under *C. partellus* infestation and damage: Postrainy season. (main stem + tiller infestation treatment).

Sorghum Line	Tiller appearance/20 plants												
	16/17 DAE	18/19	20/21	22/23	24/25	26/27	28/29	30/31	32/33	34/35	36/37	38/39	Total
IS 3492	6.0(2.4)[1]	9.7(3.1)	9.3(3.0)	10.3(3.2)	8.3(2.8)	5.3(2.2)	17.0(4.1)	15.3(3.9)	12.0(3.5)	14.0(3.7)	17.3(4.1)	24.3(4.9)	149.0
IS 9751	0(0.0)	2.0(1.4)	2.3(1.5)	3.7(1.8)	7.4(3.4)	11.3(3.3)	16.7(4.1)	13.3(3.6)	12.0(3.5)	14.7(3.8)	22.0(4.7)	28.3(5.3)	133.7
IS 19474	0(0.0)	0(0.0)	0(0.0)	2.3(1.2)	10.7(3.1)	12.3(3.5)	16.0(4.0)	11.3(3.4)	13.7(3.7)	10.3(3.2)	12.0(3.4)	13.7(3.7)	102.3
IS 19624	0(0.0)	0(0.0)	0(0.0)	1.7(1.3)	6.7(2.6)	8.3(2.9)	16.3(4.0)	9.7(3.1)	13.3(3.6)	10.7(3.3)	8.3(2.8)	11.0(3.1)	86.0
IS 19652	0(0.0)	0(0.0)	0(0.0)	0.7(0.5)	6.0(2.3)	10.7(3.3)	15.0(3.8)	17.0(4.1)	13.7(3.7)	13.0(3.9)	11.9(3.8)	13.3(3.6)	101.3
IS 22498	0(0.0)	0(0.0)	0.7(0.5)	0.7(0.7)	5.0(2.2)	8.3(2.6)	15.3(3.9)	17.3(4.2)	16.0(4.0)	16.0(4.0)	14.3(3.8)	17.3(3.9)	111.6
IS 22806	0(0.0)	0(0.0)	0.3(0.3)	4.3(2.0)	9.0(3.0)	10.7(3.2)	13.3(3.6)	10.0(3.2)	10.7(3.2)	10.3(3.2)	13.0(3.6)	13.7(3.6)	95.7
IS 25041	0.7(0.7)	1.3(0.7)	1.7(0.8)	7.0(2.6)	7.7(2.7)	20.9(4.50)	18.7(4.3)	13.7(3.7)	13.0(3.6)	15.0(3.9)	17.3(4.1)	26.0(5.1)	143.3
Mean	0.8(0.4)	1.6(0.7)	1.8(0.6)	3.8(1.7)	7.5(2.8)	11(3.2)	16.0(4.0)	13.4(3.7)	13.0(3.6)	13.0(3.6)	14.6(3.8)	18.5(4.2)	115.3
SE(±)	0.23(0.13)***	0.69(0.25)***	1.14(0.39)**	1.02(0.39)**	2.51(0.49)(NS)	5.56(0.42)(NS)	1.95(0.24)(NS)	1.16(0.15)**	1.62(0.22)(NS)	1.86(0.24)(NS)	1.66(0.24)**	2.12(0.25)***	
CV(%)	49.0(55.8)	59.9(58.5)	109.9(90.1)	46.0(40.1)	52.2(30.7)	40.6(23.2)	21.2(10.4)	15.1(73)	20.8(10.5)	25.5(11.5)	19.4(10.8)	20.4(10.6)	
$LSD_{0.05}$	0.7(0.4)	2.1(0.8)	3.5(1.2)	3.1(1.2)				3.5(0.5)			5.0(0.7)	6.4(0.5)	

DAE = Days after emergence.

1 · square root transformation.

***=Significant at 0.1%, **=Significant at 1% level, and NS=not significant.

APPENDIX K

Tiller growth in postrainy season.

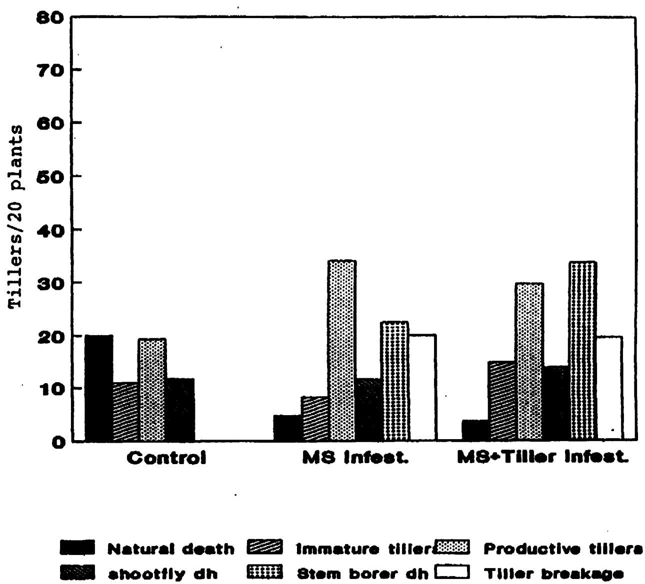
Sorghum line	Days after tiller appearance 4	8	12	16	20	24	Mean
IS 3492	6.3	12.8	16.7	20.2	28.1	38.1	20.4
IS 9751	6.5	11.1	16.8	23.0	30.2	39.2	21.1
IS 19474	5.9	11.2	18.0	29.1	41.6	54.0	26.6
IS 19624	7.3	13.5	19.6	26.3	35.5	46.4	24.8
IS 19652	8.3	14.0	21.8	29.8	38.0	48.7	26.9
IS 22498	7.0	12.2	17.7	23.7	32.2	44.0	22.8
IS 22806	8.0	11.9	17.8	25.3	39.4	52.4	25.8
IS 25041	6.7	11.2	16.1	23.9	34.4	48.7	23.5
Mean	7.0	12.2	18.1	25.2	34.9	46.4	24.0
SE(±)	1.09 NS	1.17 NS	1.73 NS	3.35 NS	3.63*	4.70*	1.86*
CV(%)	19.1	11.8	11.7	16.3	12.7	12.4	9.5
$LSD_{0.05}$					10.9	12.2	5.6

*=Significant at 5% level, NS=not significant

APPENDIX L

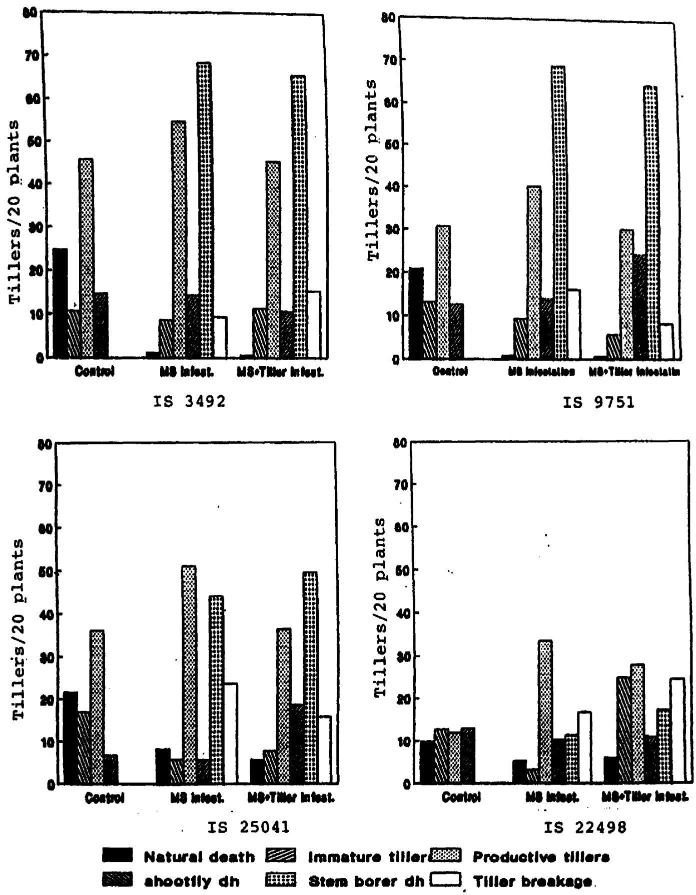
Figs. L1-L3. Fate of tillers in number/20 plants under *C. partellus* infestation: Post-rainy season.

Fig. L1. Overall fate of tillers.



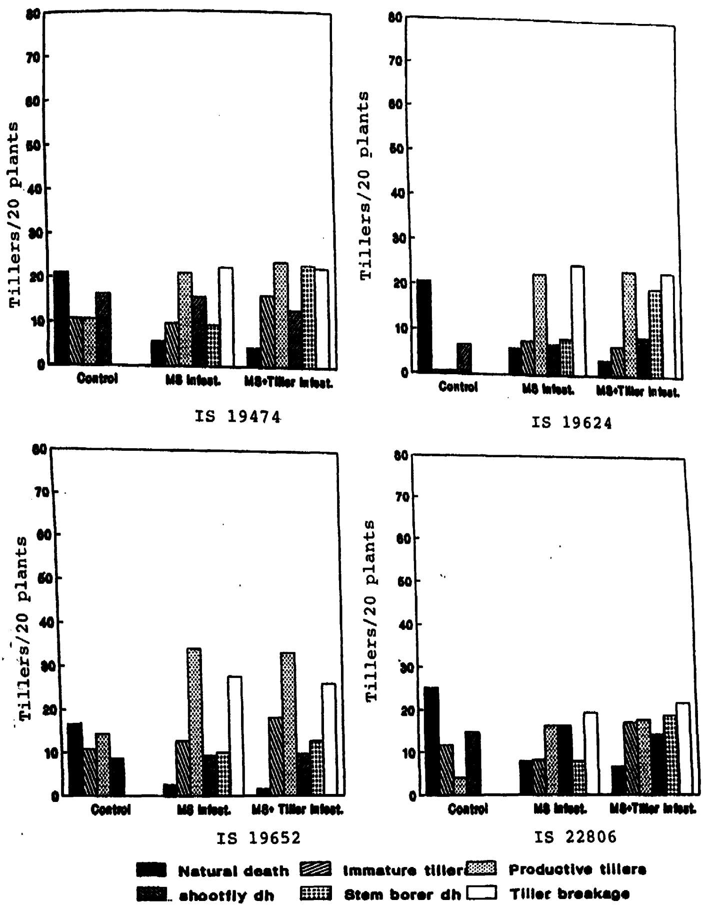
Contd..

Fig. L2. Fate of tillers in the individual lines



Contd..

Fig. L3. Fate of tillers in individual lines



APPENDIX M

Tables M1 and M6. Fate of tillers under *C. partellus* infestation: Postrainy season 1990.

M1. Percent natural tiller mortality

Sorghum line	Treatments T1	T2	T3	Mean
IS 3492	25.8	0.9	0.6	9.1
IS 9751	27.2	0.6	0.5	9.4
IS 19474	35.8	6.6	4.3	15.6
IS 19624	73.2	7.8	4.3	28.4
IS 19652	32.9	2.9	1.7	12.5
IS 22498	20.9	6.6	5.3	10.9
IS 22806	45.4	10.7	6.9	21.0
IS 25041	26.6	6.0	4.0	12.2
Mean	36.0	5.3	3.4	14.9

	SE(±)	CV(%)	$LSD_{0.05}$
For comparing treatments	0.501***	5.8	2.00
For comparing genotypes	0.966***	19.4	2.76
For comparing treat. x Gen. (within same level of treat.)	1.673***	19.4	4.78
For comparing treat. x Gen. (accross treatments)	1.643***	19.4	4.70

M2. percent immature tillers

Sorghum line	Treatments T1	T2	T3	Mean
IS 3492	11.2	5.3	7.4	8.0
IS 9751	16.9	6.4	4.3	9.2
IS 19474	18.2	11.3	15.6	15.0
IS 19624	1.7	10.1	7.7	6.5
IS 19652	21.0	13.3	17.9	17.4
IS 22498	26.5	3.9	22.2	17.5
IS 22806	20.6	10.4	17.8	16.3
IS 25041	21.1	4.1	25.4	12.5
Mean	17.1	8.1	13.2	12.8

	SE(±)	CV(%)	$LSD_{0.05}$
For comparing treatments	0.900***	12.2	3.53
For comparing genotypes	1.20***	28.1	3.43
For comparing treat. x Gen. (within same level of treat.)	2.079***	28.1	5.94
For comparing treat. x Gen. (accross treatments)	2.143***	28.1	6.12

Contd..

M3. Percent productive tiller.

Sorghum line	Treatments T1	T2	T3	Mean
IS 3492	47.5	35.0	30.8	37.8
IS 9751	39.8	27.2	22.6	29.9
IS 19474	18.1	25.5	23.1	22.2
IS 19624	1.7	29.7	27.7	19.7
IS 19652	28.2	35.3	32.7	32.1
IS 22498	25.2	41.9	24.8	30.7
IS 22806	7.2	22.0	18.5	15.9
IS 25041	44.1	36.9	25.4	35.5
Mean	26.5	31.7	25.7	28.0

	SE(±)	CV(%)	$LSD_{0.05}$
For comparing treatments	1.078***	6.7	4.23
For comparing genotypes	1.238***	13.3	3.54
For comparing treat. x Gen. (within same level of treat.)	2.144***	13.3	6.13
For comparing treat. x Gen. (accross treatments)	2.277***	13.3	6.51

M4. Percent stem borer deadheart

Sorghum Line	Treatments T1	T2	T3	Mean
IS 3492	0.0	43.7	44.2	9.1
IS 9751	0.0	45.9	47.6	31.2
IS 19474	0.0	11.1	22.6	11.2
IS 19624	0.0	10.9	22.8	11.3
IS 19652	0.0	10.3	12.6	7.6
IS 22498	0.0	13.9	15.7	9.9
IS 22806	0.0	10.4	19.5	9.9
IS 25041	0.0	31.8	34.3	22.1
Mean	0.0	22.3	27.4	16.6

	SE(±)	CV(%)	$LSD_{0.05}$
For comparing treatments	0.467***	4.9	1.83
For comparing genotypes	1.046***	18.9	2.99
For comparing treat. x Gen. (within same level of treat.)	1.811***	18.9	5.18
For comparing treat. x Gen. (accross treatments)	1.757***	18.9	5.02

Contd..

M5. Percent stem borer tiller breakage.

Sorghum line	Treatments T1	T2	T3	Mean
IS 3492	0.0	6.0	10.1	5.4
IS 9751	0.0	10.6	6.2	5.6
IS 19474	0.0	26.7	21.6	16.4
IS 19624	0.0	32.3	27.0	19.8
IS 19652	0.0	28.5	25.4	18.0
IS 22498	0.0	20.8	21.9	14.3
IS 22806	0.0	25.3	22.6	16.0
IS 25041	0.0	17.1	11.2	9.4
Mean	0.0	20.9	18.3	13.8

	SE(±)	CV(%)	$LSD_{0.05}$
For comparing treatments	1.360***	18.4	5.34
For comparing genotypes	0.877***	20.1	2.51
For comparing treat. x Gen. (within same level of treat.)	1.519***	20.1	4.34
For comparing treat. x Gen. (accross treatments)	1.967***	20.1	5.62

M6. Percent shootfly deadheart.

Sorghum line	Treatments T1	T2	T3	Mean
IS 3492	15.4	9.1	6.9	10.3
IS 9751	16.1	9.3	18.8	14.7
IS 19474	27.9	18.8	12.8	19.8
IS 19624	23.4	9.3	10.5	14.3
IS 19652	17.9	9.7	9.7	12.4
IS 22498	27.4	12.9	9.9	16.7
IS 22806	26.8	21.2	14.7	20.9
IS 25041	8.2	4.1	12.8	8.4
Mean	20.4	11.8	12.0	14.7

	SE(±)	CV(%)	$LSD_{0.05}$
For comparing treatments	1.388*	16.3	5.45
For comparing genotypes	1.238***	25.2	3.54
For comparing treat. x Gen. (within same level of treat.)	2.144***	25.2	6.12
For comparing treat. x Gen. (accross treatments)	2.439***	25.2	6.97

T1 = Control treatment, T2 = Main stem infestation,
T3 = Main stem with tiller infestation.
***=Significant at 0.1%, *=Significant at 5% level.

APPENDIX N

Table N1. Grain weight from main stems: Postrainy season.

Sorghum line	Treatment (g /20 plants) T1	T2	T3	Mean
IS 3492	307.7(20)[1]	147.3(6.0)[1]	57.0(5.0)[1]	170.6(10.3)
IS 9751	370.6(20)	150.0(5.0)	109.2(5.3)	209.9(10.1)
IS 19474	401.6(20)	180.9(7.3)	115.6(6.3)	228.2(11.7)
IS 19624	600.6(20)	246.8(7.7)	187.4(7.3)	344.9(11.1)
IS 19652	536.2(20)	144.2(6.7)	154.0(6.7)	278.2(12.8)
IS 22498	245.4(20)	113.1(10.0)	94.0(8.3)	150.8(11.7)
IS 22806	388.0(20)	142.2(7.0)	154.6(8.0)	228.2(11.2)
IS 25041	257.1(20)	93.5(10.7)	92.5(10.0)	147.7(13.6)
Mean	288.4(20)	152.3(7.5)	120.5(7.1)	220.4(11.6)

	SE(+)	CV(%)	$LSD_{0.05}$
For comparing treatments	7.41***	5.8	28.9
For comparing genotypes	14.27***	19.4	41.4
For comparing treat. x Gen. (within same level of treat.)	5.68**	10.4	16.2
For comparing treat. x Gen. (accross treatments)	5.73**	10.4	16.4

Table N2. Grain weight from tillers: Postrainy season.

Sorghum line	Treatment (g /20 plants) T1	T2	T3	Mean
IS 3492	358.6(45.7)[1]	336.6(54.7)[1]	306.5(45.3)[1]	334.0(48.6)
IS 9751	253.0(30.7)	206.6(40.3)	181.1(31.3)	213.4(34.1)
IS 19474	77.9(10.7)	252.0(21.0)	200.6(23.7)	176.8(18.4)
IS 19624	15.3(0.7)	304.4(22.7)	428.7(24.7)	249.5(16.0)
IS 19652	219.6(14.3)	605.2(34.0)	506.3(33.0)	443.7(27.1)
IS 22498	245.5(12.0)	215.2(33.3)	195.9(27.7)	218.9(24.3)
IS 22806	45.60(4.0)	82.4(16.3)	165.8(17.7)	131.3(12.7)
IS 25041	299.6(36.0)	309.2(51.0)	273.1(36.3)	294.0(41.1)
Mean	189.4(19.3)	301.4(34.2)	282.3(29.7)	257.7(27.7)

	SE(+)	CV(%)	$LSD_{0.05}$
For comparing treatments	11.14**	7.5	43.4
For comparing genotypes	15.70***	18.3	45.5
For comparing treat. x Gen. (within same level of treat.)	27.20***	18.3	78.9
For comparing treat. x Gen. (accross treatments)	27.77***	18.3	80.5

T1 = Control treatment, T2 = Main stem infestation,
T3 = Main stem with tiller infestation.
1 - Number of heads.
***=Significant at 0.1%, **=Significant at 1% level.

APPENDIX O

Percent reduction in grain yield due to *C. partellus* infestation

	Treatments (%)					
	T2		T3		Mean	
Sorghum line	PR	RS	PR	RS	PR	RS
IS 3492	27.3	54.9	45.4	54.5	36.4	54.4
IS 9751	42.9	48.3	53.4	40.2	48.2	44.2
IS 19474	9.3	46.1	34.0	46.1	21.9	46.1
IS 19624	10.5	37.0	0.0	44.7	5.2	40.9
IS 19652	0.8	54.3	12.6	68.9	6.7	61.6
IS 22498	33.1	31.7	41.0	25.3	37.0	28.5
IS 22806	25.1	45.3	26.1	62.5	25.6	53.9
IS 25041	27.6	17.8	34.3	26.2	31.0	18.9
ICSV 700	-	20.0	-	24.2	-	22.2
CSH 1	-	72.0	-	78.4	-	75.2

T2= Main stem infestation, T3= Main stem with tiller infestation, PS= Post-rainy, and RS= rainy season.

1- % Reduction (T2) = T1 - T2 / T1 * 100

2- % Reduction (T3) = T1 - T3 / T1 * 100

T1= Control treatment

APPENDIX P

Correlation coefficients of a number of characters studied in rainy season.

Character			r- value
DH% (T2)	vs	MS height	-0.48* (1)
DH% (T3)	vs	MS height	-0.56* (1)
DH% (T2)	vs	Boot stage	0.62* (1)
DH% (T3)	vs	Boot stage	0.34 NS (1)
DH% in tillers 14 day-old	vs	Tiller length 24 day-old (T1)	-0.47* (1)
DH% (T2)	vs	% Reduction in grain yield (T2)	0.47 NS (2)
DH% (T3)	vs	% Reduction in grain yield (T3)	0.78* (2)
DH% ($\bar{X}$)	vs	% Reduction in grain yield ($\bar{X}$)	0.67* (2)

DH= Deadheart, MS= Main stem, T1= control, T2= Main stem infestation, T3= Main stem with tiller infestation treatment.
(1)- r-value tested at 22 degrees of freedom.
(2)- r-value tested at 8 degrees of freedom.
($\bar{X}$)= Mean of T2 and T3.

*=Significant at 5% level and NS=not significant.

APPENDIX Q

Total number of basal tillers produced in the control and infested treatments : Rainy season.

Sorghum line	Treatments (tillers / 10 plants) T1	T2	T3	Mean
IS 3492	27.3	36.3	34.7	32.7
IS 9751	22.0	34.3	32.3	29.6
IS 19474	19.7	50.3	56.3	42.1
IS 19624	14.0	40.0	40.7	31.6
IS 19652	15.7	35.3	59.7	36.9
IS 22498	27.0	38.3	43.7	36.3
IS 22806	21.3	47.7	56.0	41.7
IS 25041	27.0	31.7	38.7	32.4
ICSV 700	2.0	8.3	8.7	6.3
CSH 1	1.3	28.3	30.3	20.0
Mean	17.7	35.1	40.1	31.

	SE (±)	CV (%)	LSD 0.05
For comparing treatments	0.8***	3.4	3.0
For comparing genotypes	2.1**	14.5	5.9
For comparing treatment x genotype (within same level of treatment)	3.7**	14.5	10.5
For comparing treatment x genotype (across treatments)	3.7**	14.5	10.5

T1= Control treatment, T2= Main stem infestation, and T3= Main stem with tiller infestation.

***=Significant at 0.1% and **=significant at 1% level.

APPENDIX R

Pattern of tiller appearance under C. partellus infestation : Rainy season.

Sorghum line	Tillers/10 plants											
	9/10 DAE	11/12	13/14	15/16	31/32	33/34	35/36	37/38	30/40	41/42	43/44	45/46
IS 3492	6.7(2.6)[1]	07.7(2.8)	08.0(2.8)	5.3(2.2)	1.3(0.9)	06.0(2.0)	1.7(1.3)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.0(0.0)
IS 9751	5.3(2.3)	06.7(2.6)	04.3(2.0)	6.0(2.4)	2.7(1.5)	03.7(1.9)	2.3(1.5)	0.7(0.5)	0.3(0.3)	0.0(0.0)	0.0(0.0)	0.0(0.0)
IS 19474	0.0(0.0)	10.7(3.3	10.3(3.2)	4.0(2.0)	7.3(2.7)	10.0(3.1)	3.7(1.5)	4.0(2.0)	3.7(1.9)	1.7(1.2	0.7(0.7)	0.3(0.3)
IS 19624	0.0(0.0)	05.7(2.4)	09.0(3.0)	4.0(2.0)	1.7(1.1)	08.7(2.9)	4.7(2.7)	5.3(2.3)	2.3(1.5)	0.3(0.3)	0.0(0.0)	0.0(0.0)
IS 19652	0.0(0.0)	04.3(2.0)	07.0(2.6)	4.0(2.0)	6.3(2.5)	10.0(3.1)	5.0(2.0)	6.7(2.6)	4.7(2.1)	6.3(2.5)	4.3(2.1)	1.0(0.6)
IS 22498	1.3(0.9)	15.7(3.9)	04.7(2.1)	4.0(2.0)	4.0(2.0)	07.3(2.7)	4.0(2.0	2.3(1.5)	0.3(0.3)	0.0(0.0)	0.0(0.0)	0.0(0.0)
IS 22806	0.0(0.0)	11.0(3.2)	08.7(2.8)	4.0(2.0)	6.0(2.0)	07.7(2.8)	4.7(2.1)	4.7(2.2)	3.0(1.7)	2.0(1.2)	2.3(1.5)	1.7(1.0)
IS 25041	7.3(2.7)	10.3(3.2)	02.0(1.1)	4.0(2.0)	0.3(0.3)	00.7(0.1)	3.7(1.9)	4.3(2.0)	2.7(1.6)	2.0(1.4)	1.0(0.8)	0.3(0.3)
ICSV 700	0.0(0.7)	00.0(0.0)	00.3(0.3)	1.0(1.0)	0.0(0.0)	00.0(0.0)	4.0(1.9)	1.7(1.2)	1.7(1.0)	0.0(0.0)	0.0(0.0)	0.0(0.0)
CSH 1	0.0(0.0)	00.3(0.3)	00.7(0.5)	1.0(0.8)	0.0(0.0)	00.0(0.0)	7.3(2.7)	7.3(2.7)	4.7(2.2)	1.7(1.0)	2.3(1.5)	0.0(0.0)
Mean	2.1(0.8)	7.2(2.4)	5.5(2.0)	3.7(1.8)	3.0(1.3)	6.0(2.2)	4.1(1.9)	3.7(1.7)	2.3(1.3)	1.4(0.8)	1.1(0.7)	0.3(0.3)
SE (±)	00.6(00.2)***	02.3(00.4)**	02.2(00.6)**	01.3.(00.3)*	01.2(00.5)***	01.7(00.3)**	01.4(00.4)*	01.4(00.4)***	01.1(00.4)*	01.0(00.4)*	00.6(00.3)**	00.4(000.3)**
CV (%)	35.0(34.4)	39.4(22.6)	48.4(33.3)	42.0 (22.8)	50.0(42.2)	35.1(18.8)	41.2(27.5)	47.3(27.5)	56.5(38.8)	87.3(65.6)	71.9(54.4)	140.2(135.3)
LSD 0.5	01.8(0.7)	06.8(01.7)	06.5(01.8)	03.9(00.9)	03.6(01.5)	5.0(0.9)	4.2(1.2)	4.2(1.2)	3.3(1.2)	3.0(1.2)	1.8(0.9)	1.2(0.9)

1 = Square root transformation.

DAE = Days after emergence.

***=Significant at 0.1%, ** = Significant at 1%, and *=Significant at 5% level. NS=not significant.

APPENDIX S

Tiller data recorded in rainy season.

Sorghum line	Leaf-feeding score 14 (day-old)	21	28	Deadheart(%) 14 (day-old)	21	28	Boot stage
IS 3492	7.7	-	-	43.3	-	-	35.1
IS 9751	6.3	-	-	56.7	-	-	37.4
IS 19474	7.7	5.7	5.7	83.3	23.3	6.7	43.1
IS 19624	5.7	3.7	-	76.7	36.7	-	34.7
IS 19652	6.3	5.7	-	53.3	30.0	-	34.3
IS 22498	5.7	-	-	53.3	-	-	37.0
IS 22806	7.0	5.7	4.3	76.7	30.0	13.3	42.5
IS 25041	4.3	-	-	80.0	-	-	47.9
ICSV 700	6.3	-	-	-	-	-	-
CSH 1	6.3	7.0	-	56.7	53.3	-	30.9
Mean	6.3	5.5	5.0	64.4	34.7	10.0	38.1
SE (±)	0.8 NS	1.1 NS	0.9 NS	5.9**	10.6 NS	4.7 NS	3.1**
CV (%)	21.4	24.7	23.1	15.8	37.4	57.7	9.8
LSD 0.05				17.5			9.2

**=Significant at 1% level. NS=not significant.

APPENDIX T

Tillers growth (cm) : Rainy season.

Sorghum line	Days after tiller appearance 4		8		12		16		20		24	
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
IS 3492	14.7	20.3	30.5	35.7	50.7	52.1	65.9	68.4	83.3	82.8	119.2	109.5
IS 9751	16.5	21.8	33.3	37.3	50.0	55.7	62.1	71.1	81.1	87.5	110.9	110.7
IS 19474	11.5	23.4	23.0	39.7	34.3	63.2	39.7	90.2	51.6	106.3	62.3	133.3
IS 19624	14.0	20.2	28.6	38.1	36.4	53.4	40.9	71.3	43.7	85.3	46.5	96.7
IS 19652	14.3	20.6	29.5	38.2	40.3	60.7	48.4	69.2	61.2	81.4	70.2	89.4
IS 22498	14.5	29.4	30.0	36.7	45.3	59.1	51.4	78.8	57.4	92.6	63.5	100.9
IS 22806	13.0	22.5	26.5	40.1	36.1	68.0	45.4	93.1	53.8	113.5	59.9	138.9
IS 25041	15.1	18.6	30.0	39.5	45.3	62.0	56.1	85.0	65.9	115.2	72.4	137.2
ICSV 700	-	-	-	-	-	-	-	-	-	-	-	-
CSH 1		21.4	-	43.3	-	54.3	-	66.2	-	77.8	-	99.0
Mean	14.2	22.0	28.9	38.7	42.3	58.7	51.3	77.0	62.3	93.6	75.6	112.8
SE (±)	1.3*	5.4NS	2.0**	3.8NS	2.4**	6.5NS	3.0***	6.9**	4.7***	8.7**	8.6***	4.2***
CV (%)	11.0	30.2	0.4	12.0	6.8	13.6	7.1	11.0	9.2	11.4	13.9	4.6
LSD0.05	3.9		5.9		7.1		8.9	20.5	14.0	25.0	25.5	12.5

T1 = Control, T2 = Main stem infestation treatment.

***=Significant at 0.1%, **=Significant at 1%, and *=Significant at 5% level. NS=not significant.

APPENDIX U

Grain yield from main stem (g/10 plants) : Rainy season .

Sorghum line	Treatments T1	T2	T3	Mean
IS 3492	259.4 (10)	101.5 (6.0)	65.5 (5.3)	142.1
IS 9751	202.8 (10)	94.5 (5.7)	95.4 (5.3)	130.9
IS 19474	280.6 (10)	7.9 (0.3)	14.0 (1.0)	100.8
IS 19624	351.9 (10)	115.7 (2.7)	92.4 (2.7)	186.7
IS 22498	208.0 (10)	72.7 (4.7)	75.5 (4.3)	118.7
IS 22806	347.4 (10)	14.5 (0.7)	7.9 (0.7)	123.2
IS 25041	212.4 (10)	86.0 (5.7)	78.5 (5.7)	125.6
ICSV 700	127.6 (10)	98.1 (7.7)	88.5 (7.7)	104.7
CSH 1	418.0 (10)	58.5 (2.7)	21.2 (1.3)	165.9
Mean	276.6	69.7	56.0	134.1

	SE (±)	CV (%)	LSD 0.05
For comparing treatments	5.3**	4.0	21.0
For comparing genotypes	13.7**	21.7	38.7
For comparing treatment x genotypes (within same level of treatment)	23.7**	21.7	67.0
For comparing treatment x genotype (across treatments)	23.1*	21.7	65.3

T1= Control, T2= Main stem infestation, and T3= Main stem with tiller infestation.

Figures in parenthesis indicate number of heads.

**=Significant at 1% and *=significant at 5% level.

APPENDIX V

Grain yield from tillers (g/10 plants) : Rainy season

Sorghum line	Treatments T1	T2	T3	Mean
IS 3492	139.9	79.3	117.2	112.1
IS 9751	57.7	41.2	56.9	51.9
IS 19474	0.0	139.8	136.3	92.1
IS 19624	0.0	106.5	101.4	69.3
IS 19652	72.2	143.7	112.8	109.6
IS 22498	42.8	90.5	104.9	79.4
IS 22806	0.0	167.9	109.9	92.5
IS 25041	0.0	88.2	71.6	53.2
ICSV 700	0.0	3.5	8.3	3.9
CSH 1	0.0	58.9	69.8	42.9
Mean	31.3	91.9	88.9	70.7

	SE (±)	CV (%)	LSD 0.05
For comparing treatments	4.8**	8.3	19.0
For comparing genotypes	11.9**	35.8	33.7
For comparing treatment x genotype (within same level of treatment)	20.7**	35.8	58.5
For comparing treatment x genotype (across treatments)	20.2**	35.8	57.1

T1= Control, T2= Main stem infestation, and T3= Main stem with tiller infestation.

***=Significant at 1% level.

APPENDIX W

Two season analysis of variance : Number of basal tillers per plant .

Source of variation	DF	SS	MS	VR
Replication, season, stratum.				
Season	1	52.9	52.9	37.3**
Residual	4	5.7	1.4	
Total	5	59.6	11.7	
Replication, Season, treatment, stratum.				
Treatment	2	169.1	84.6	310.1***
Season x treatment	2	1.6	0.9	2.9NS
Residual	8	2.2	0.3	
Total	12	172.8	14.4	
Replication,season,treatment,entry,stratum.				
Entry	7	36.2	5.2	15.9***
Season x entry	7	83.1	11.9	36.5***
Treatment x entry	14	20.3	1.5	4.5***
Season x treatment x entry	14	15.1	1.1	3.3***
Residual	84	27.3	0.3	
Total	126	182.1	1.4	
Grand total	143	413.6		

DF= Degrees of feedom
SS= Sum of squares
MS= Mean squares
VR= Variance ratio.

***=Significant at 0.1%, **=significant at 1% level. NS=not significant.

APPENDIX X

Two season analysis of variance : Percent contribution of tillers in total grain yield.

Source of variation	DF	SS	MS	VR
Replication, season, stratum.				
Season	1	15380.5	15380.5	54.6***
Residual	4	1127.0	281.8	
Total	5	16507.5	3301.5	
Replication, Season, treatment, stratum.				
Treatment	2	68012.1	34006.1	2143.3***
Season x treatment	2	1341.9	670.9	42.3
Residual	8	126.9	15.9	
Total	12	69480.9	5790.1	
Replication,season,treatment,entry, stratum.				
Entry	7	6711.7	958.8	17.5***
Season x entry	7	13477.5	1925.4	35.1***
Treatment x entry	14	13362.8	954.5	17.4***
Season x treatment x entry	14	4753.5	339.5	6.2***
Residual	83(1)	4549.5	64.8	
Total	125	42854.9	342.8	
Grand total	142	128843.4		

DF= Degrees of feedom
SS= Sum of squares
MS= Mean squares
VR= Variance ratio.

****=Significant at 0.1% level.

APPENDIX Y

Results of pot studies on insect-induced tillering.[1]

X vs Y			Genotype	X	Y	X-Y	T-value	Probability
No. of tillers per plant (control)	vs	no. of tillers per plant (infested)	CSH 1	0.0	4.3	-4.3	-15.5	0.0001***
			IS 19624	1.0	3.9	-2.9	-9.7	0.0006***
No. of tillers per plant (control)	vs	no. of tillers per plant (mechanical damage)	CSH 1	0.0	3.3	-3.3	-15.2	0.0001***
			IS 19624	1.0	2.8	-1.8	-8.7	0.0009***
No. of tillers per plant (infested)	vs	no. of tillers per plant (mechanical damage)	CSH 1	4.3	3.3	1.0	3.1	0.03*
			IS 19624	3.9	2.8	1.1	4.0	0.01*
Date of DH[2] appearance (infested)	vs	Date of DH[3] appearance (mechanical damage)	CSH 1	9.0	1.0	8.0	6.2	0.003**
			IS 19624	6.0	1.0	5.0	29.0	0.00001***
DH (%) (infested)	vs	DH (%) (mechanical damage)	CSH 1	83.3	91.7	-8.4	-1.0	0.37 NS
			IS 19624	91.7	91.7	0.0	-	-

1- Results based on six replication

2- In days after release of larvae in the cage

3- In days after mechanical damage

DH= Deadheart

***=Significant at 0.1%, **= Significant at 1%, *= Significant at 5% level, NS=not significant.