UNIVERSIDADE FEDERAL DE LAVRAS

CAMILA DA SILVA FERNANDES SOUZA

SORGHUM (*Sorghum bicolor*): A STUDY OF THE RESISTANCE TO CROP PESTS IN BRAZIL

LAVRAS – MG
2021

CAMILA DA SILVA FERNANDES SOUZA

SORGHUM (*Sorghum bicolor*): A STUDY OF THE RESISTANCE TO CROP PESTS IN BRAZIL

Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Entomologia, área de concentração em Entomologia, para a obtenção do título de Doutor.

Prof. Dr. Bruno Henrique Sardinha de Souza
Orientador

Dra. Simone Martins Mendes
Coorientadora

LAVRAS – MG
2021

Ficha catalográfica elaborada pelo Sistema de Geração de Ficha Catalográfica da Biblioteca Universitária da UFLA, com dados informados pelo(a) próprio(a) autor(a).

Souza, Camila da Silva Fernandes.
SORGHUM (*Sorghum bicolor*): A study of the resistance to crop pests in Brazil / Camila da Silva Fernandes Souza. - 2021.
109 p. : il.

Orientador(a): Bruno Henrique Sardinha de Souza.
Coorientador(a): Simone Martins Mendes.
Tese (doutorado) - Universidade Federal de Lavras, 2021.
Bibliografia.

1. Resistência de plantas à insetos. 2. cultura do sorgo. 3. Pragas do sorgo. I. de Souza, Bruno Henrique Sardinha. II. Mendes, Simone Martins. III. Título.

CAMILA DA SILVA FERNANDES SOUZA

SORGO (*Sorghum bicolor*): UM ESTUDO DA RESISTÊNCIA À INSETOS-PRAGA NO BRASIL

SORGHUM (Sorghum bicolor): A STUDY OF THE RESISTANCE TO CROP PESTS IN BRAZIL

Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Entomologia área de concentração em Entomologia, para a obtenção do título de Doutor.

APROVADA em 21 de setembro de 2021.

Dra. Ana Paula Schneid Afonso Da Rosa	EMBRAPA CLIMA TEMPERADO
Dr. Carlos Juliano Brant Albuquerque	UFMG
Dr. Ivênio Rubens de Oliveira	EMBRAPA MILHO E SORGO
Dr. Marcos Antônio Matiello Fadini	UFSJ

Prof. Dr. Bruno Henrique Sardinha de Souza
Orientador

Dra. Simone Martins Mendes
Coorientadora

LAVRAS – MG
2021

A minha filha Lara, meu maior amor.

Ao meu marido Thiago e aos meus pais Ronaldo (in memorian) e Wania pelo amor, cuidado, carinho e apoio incondicional.

Dedico

AGRADECIMENTOS

Primeiramente a Deus por nunca me abandonar.
A Universidade Federal de Lavras pela oportunidade de ingressar no programa de Pós-Graduação em Entomologia.
A Embrapa Milho e Sorgo por ceder suas dependências para realização do trabalho.
A Doutora Simone Martins Mendes pela dedicada orientação, importantes oportunidades, carinho, apoio, valiosos ensinamentos e ajuda de sempre.
Ao Professor Doutor Bruno Henrique Sardinha de Souza pela orientação, apoio, confiança, oportunidade e disponibilidade.
Aos Professores Doutores Carlos Juliano Brant Albuquerque, Ivênio Rubens de Oliveira, Marcos Antônio Matiello Fadini e Ana Paula Schneid Afonso Da Rosa pela presença na banca, contribuindo grandemente com o trabalho.
Aos amigos do Laboratório de Ecotoxicologia e Manejo de Insetos da Embrapa Milho e Sorgo, Lorena, Nathália, Michele, Clareana, Caio, Amanda, Camila, Marcos, Matheus, Patrick, Guilherme, Eustáquio, pelas ajudas experimentais e grandes alegrias no convívio no dia-a-dia de trabalho.
Aos meus amados pais Ronaldo (in memorian) e Wania pelo grandioso apoio, e enorme amor.
Aos meus irmãos Raphael, Daniel e Bruno pelo grande apoio, carinho e paciência.
Ao meu marido Thiago pelo carinho, apoio, paciência, dedicação e amor.
A todos os meus amigos pelos momentos de descontração, apoio e carinho. Aos meus amigos do curso de Entomologia pelo apoio, momentos de descontração, companhia e ajuda nos estudos.
Aos colegas, funcionários, professores e pesquisadores da Universidade Federal de Lavras e Embrapa Milho e Sorgo.
A Fundação de Amparo à Pesquisa de Minas Gerais (FAPEMIG) pela bolsa de doutorado. O presente trabalho, bem como os artigos derivados desta tese, foram realizados com apoio da Fundação de Amparo à Pesquisa de Minas Gerais (FAPEMIG).

MUITO OBRIGADA!

RESUMO

As interações inseto-planta envolvem mecanismos de sobrevivência, seleção genes de resistência de plantas e quebra dessa resistência por insetos. De tais interações resultam o desenvolvimento de mecanismos de defesa nas plantas os quais fazem pressão de seleção sobre os insetos, caracterizando processos coevolutivos. Esta tese reuniu três artigos com a cultura do sorgo visando a resistência às principais pragas. No primeiro artigo o objetivo foi avaliar a suscetibilidade do sorgo *bmr*-6 um genótipo mutante com menor concentração de lignina às pragas *Diatraea saccharalis* e *Spodoptera frugiperda*. Foram realizados experimentos em laboratório e casa-de-vegetação, avaliando o desenvolvimento destas pragas nos híbridos de sorgo biomassa *bmr* 007, 008, TX635 e seus respectivos genótipos isogênicos convencionais (sem o gene *bmr*). O teor de lignina foi maior nos híbridos não *bmr*. A menor sobrevivência de *S. frugiperda* foi verificada no híbrido BR008 tanto *bmr* quanto não *bmr*. As notas de injúria por *S. frugiperda* no sorgo em casa-de-vegetação foram altas (>7) em todos os híbridos. Para *D. saccharalis*, não houve diferença significativa para a sobrevivência larval em laboratório, mas em casa de vegetação o híbrido BR007 tanto *bmr* quanto não *bmr* proporcionaram maior sobrevivência. O segundo artigo teve como objetivo avaliar a influência da infestação *D. saccharalis* sobre a produção de grãos em híbridos comerciais. Para isso, híbridos de sorgo granífero foram plantados em três safras: março de 2018 (2018/1) (SAFRA 1), setembro de 2018 (2018/2) (SAFRA 2) e março de 2019 (2019/1) (SAFRA 3). No experimento, foram utilizados seis tratamentos, sendo os três híbridos de sorgo granífero e os mesmos três híbridos com tratamento químico com o produto Altacor® (150 ml ha^{-1}), sob infestação natural, em quatro repetições. Os parâmetros avaliados foram: comprimento das galerias (cm), altura da planta (cm), comprimento (cm) e peso (g) das panículas, intensidade da infestação e produtividade. A intensidade de infestação das três safras foi maior quando não tratada com inseticida e resultou em menor produtividade. Em relação à diferença entre as safras, o plantio da 1ª safra apresentou menor intensidade de infestação. O híbrido DKB 590 apresentou o menor nível de tolerância, sendo que com inseticida a produção aumentou 1,5 vezes na safra 1 (149,77%). Na safra 2, o híbrido BRS 373 apresentou o menor aumento na produtividade de grãos com controle (29,79%), seguido pelo AG1090 com 33,13%, e novamente DKB 590 (40,79%) com maior dependência de controle químico para aumentar a produtividade. A safra 3 obteve o menor rendimento entre as três safras, e o híbrido AG1090 respondeu melhor ao controle químico com aumento de 105,90% no rendimento, seguido pelo DKB 590 com 54,26% e BRS373 com 38,19%. O terceiro artigo avaliou a suscetibilidade de 30 híbridos de sorgo granífero a *S. frugiperda*, *D. saccharali*s e *Diceraeus melacanthus* em casa-de-vegetação. Para a lagarta-do-cartucho, a avaliação nas plantas foi realizada 7 e 14 dias após a infestação (DAI). Para a *D. saccharalis* em 40 DAI e para o percevejo barriga-verde aos 12, 19 e 26 dias após a infestação. Por meio da análise de agrupamento, foi possível separar os híbridos de sorgo granífero em grupos quanto aos níveis de resistência a cada praga. O híbrido BRS373 se destacou como moderadamente resistente a *S. frugiperda*; os AG1090, 80G20, BRAVO, BRS373, AG1615 e IG220 foram os mais promissores para *D. saccharalis*; e para *D. melacanthus*, os híbridos 50A40, A9735R, JADE, ENFORCER, BUSTER, 50A10 e IG244 foram os mais indicados. Conclui-se que o sorgo é suscetível as três espécies aqui estudadas, a seleção de híbridos é específica para cada espécie, o menor teor de lignina no sorgo não deixa a planta mais suscetpivel a *D. saccharalis* e *S. frugiperda*, e o sorgo granífero pode ser muito sensível ao ataque de *D. saccharalis*, diminuindo a produtividade em até 1,5 vezes dependendo do híbrido, época de plantio, falta de monitoramento e controle adequado.

Palavras-chave: Resistência de plantas. *Spodoptera frugiperda*. *Diatraea saccharalis*. *Diceraeus melacanthus*. Sorgo. Granífero. Sorgo energia.

ABSTRACT

The insect-plant interactions involve survival mechanisms, selection of plant resistance genes and the breaking of this resistance by insects. These interactions result in the development of defense mechanisms in plants which exert selection pressure on insects, characterizing coevolutionary processes. This thesis brought together three articles on the sorghum crop aiming at resistance to the main pests. In the first article, the objective was to evaluate the susceptibility of sorghum *bmr*-6, a mutant genotype with a lower concentration of lignin, to the pests *Diatraea saccharalis* and *Spodoptera frugiperda*. Experiments were carried out in laboratory and greenhouse, evaluating the development of these pests in sorghum biomass hybrids *bmr* 007, 008, TX635 and their respective conventional isogenic genotypes (without the *bmr* gene). The lignin content was higher in non-*bmr* hybrids. The lowest survival of *S. frugiperda* was verified in the hybrid BR008 both *bmr* and non-*bmr*. Injury scores by *S. frugiperda* in sorghum in greenhouse were high (>7) in all hybrids. For *D. saccharalis*, there was no significant difference for larval survival in the laboratory, but in the greenhouse the hybrid BR007 both bmr and non-bmr provided greater survival. The second article aimed to evaluate the influence of *D. saccharalis* infestation on grain production in commercial hybrids. For this purpose, grain sorghum hybrids were planted in three crops: March 2018 (2018/1) (CROP SEASON 1), September 2018 (2018/2) (CROP SEASON 2) and March 2019 (2019/1) (CROP SEASON 3). In the experiment, six treatments were used, being the three hybrids of grain sorghum and the same three hybrids with chemical treatment with the product Altacor® (150 ml ha-1), under natural infestation, in four replications. The parameters evaluated were: length of galleries (cm), plant height (cm), length (cm) and weight (g) of panicles, infestation intensity and productivity. The infestation intensity of the three crops seasons was higher when not treated with insecticide and resulted in lower productivity. Regarding the difference between crops seasons, the planting of the 1st crop season showed lower infestation intensity. The hybrid DKB 590 had the lowest tolerance level, and with insecticide production increased 1.5 times in crop season 1 (149.77%). In crop season 2, hybrid BRS 373 showed the smallest increase in grain yield with control (29.79%), followed by AG1090 with 33.13%, and again DKB 590 (40.79%) with greater dependence on chemical control to increase productivity. Thw crop season 3 had the lowest yield among the three crops, and the hybrid AG1090 responded better to chemical control with a 105.90% increase in yield, followed by DKB 590 with 54.26% and BRS373 with 38.19%. The third article evaluated the susceptibility of 30 grain sorghum hybrids to *S. frugiperda*, *D. saccharalis* and *Diceraeus melacanthus* in a greenhouse. For fall armyworm, plant evaluation was performed 7 and 14 days after infestation (DAI). For *D. saccharalis* at 40 DAI and for the green-bellied stink bug at 12, 19 and 26 days after infestation. Through cluster analysis, it was possible to separate grain sorghum hybrids into groups according to the levels of resistance to each pest. The BRS373 hybrid stood out as moderately resistant to *S. frugiperda*; AG1090, 80G20, BRAVO, BRS373, AG1615 and IG220 were the most promising for *D. saccharalis*; and for *D. melacanthus*, the hybrids 50A40, A9735R, JADE, ENFORCER, BUSTER, 50A10 and IG244 were the most indicated. It is concluded that sorghum is susceptible to the three species studied here, the selection of hybrids is specific for each species, the lower lignin content in sorghum does not make the plant more susceptible to *D. saccharalis* and *S. frugiperda*, and grain sorghum it can be very sensitive to *D. saccharalis* attack, decreasing productivity by up to 1.5 times depending on the hybrid, planting time, lack of monitoring and adequate control.

Keywords: Plant resistance. *Spodoptera frugiperda*. *Diatraea saccharalis*. *Diceraeus melacanthus*. grain sorghum. energy sorghum.

SUMÁRIO

PRIMEIRA PARTE

1 INTRODUÇÃO

As interações inseto-planta envolvem mecanismos de sobrevivência, selecionando genes de resistência da planta e quebra dessa resistência pelos insetos num processo de coevolução. Essas interações resultam no desenvolvimento de mecanismos de defesa nas plantas. Como por exemplo, as defesas químicas as quais fazem pressão de seleção sobre os insetos. Estes, por sua vez, desenvolvem mecanismos de desintoxicação das defesas químicas, proporcionando nova pressão de seleção sobre as plantas, que contra-atacam com a produção de outros compostos químicos (EHRLICH; RAVEN, 1964). Dessa forma, estudar os padrões comportamentais e biológicos de insetos-praga em suas plantas hospedeiras torna-se necessário para o entendimento da preferência e desenvolvimento do inseto, bem como da resposta da planta diante da injúria (KNOLHOFF; HECKEL, 2013), e assim. proporcionar conhecimentos para aplicação da tática de resistência de planats no Manejo Integrado de Pragas (MIP).

A resistência de plantas a insetos, em função de sua natureza poligênica na maioria dos casos, pode se manifestar em diferentes níveis: alta resistência, moderada resistência, suscetibilidade e alta suscetibilidade (BALDIN et al.,2019). A resistência de plantas, seja de forma convencional ou transgênica, é uma das táticas preconizadas dentro do MIP, uma vez que apresenta como uma das principais vantagens a associação compatível com as demais táticas de manejo. Como é conhecido, as plantas possuem diferenças quanto à suscetibilidade a pragas. Isto é, um fenótipo pode apresentar maior ou menor resistência (ou suscetibilidade) ao ataque de insetos-praga, que pode ser expressa de forma constitutiva ou induzida (GATEHOUSE, 2002; BASTOS et al., 2015). Em todas as culturas cultivadas em alta escala é possível trabalhar a resistência de plantas a insetos.

O sorgo, *Sorghum bicolor* (L.) Moench, é o quinto cereal mais produzido no mundo, usado como grãos, forragem e energia. Pelos diversos tipos de sorgo e sua ampla variabilidade genética, estudos de avaliação de resistência ainda são insipientes. Além disso, a resistência de plantas se adapta e integra de forma compatível às demais táticas de controle de pragas dentro dos preceitos do MIP, possui interação com o controle biológico e químico, aumentando sua eficiência, interferindo menos com as outras táticas de controle e com o ambiente.

O sorgo biomassa é uma matéria-prima lignocelulósica promissora por ser uma cultura produtiva e adaptada a condições de estresse hídrico, o que é uma vantagem em um cenário que demanda economia de água, além de ter um sistema de produção já bem conhecido e ser adaptado a diferentes condições ambientais (SILVA et al. 2017). O sorgo biomassa *brown midrib mutan*t (*bmr*) é uma alternativa ao setor energético para uso em processos em que a lignina representa um obstáculo, como por exemplo para a produção de etanol de segunda geração. Para esta finalidade, a matéria-prima precisa ter baixo teor de lignina, como nesse mutante de sorgo *bmr*, pois a celulose é um polímero de glicose que necessita ser quebrado para este processo. No entanto, a lignina nas plantas pode ser um fator de resistência às pragas, sobretudo lepidópteros (DOW et al. 2016).

O sorgo granífero pode substituir o milho em rações para alimentação animal, como alimento base de pessoas em regiões da África e Ásia, além de ser promissor para alimentação humana em função de ser rico em compostos bioativos, funcionais e não conter glúten (WAQUIL, et al., 2003; FAO, 1995; MARTINO et al., 2014. O Brasil é atualmente o 9º maior produtor mundial, sendo responsável por aproximadamente 10% da produção de sorgo granífero do mundo. Na safra 2019 no país foram produzidas quase 2,5 milhões de toneladas de grãos de sorgo, com destaque para o estado de Goiás que representa mais de 40% da produção nacional, seguido por Minas Gerais (IBGE, 2020).

A ocorrência de insetos-praga representa um problema à cultura do sorgo. A broca-da-cana *Diatraea saccharalis* (Fabricius, 1794) (Lepidoptera: Crambidae) é uma das principais pragas da cultura, cujo maior prejuízo para uma planta que pode alcançar cinco metros de altura é tornar o colmo frágil e suscetível ao tombamento, além de dificultar o fluxo de seiva e fotoassimilados na planta (MENDES et al. 2014; SILVA et al. 2017). A lagarta-do-cartucho *Spodoptera frugiperda* (Smith, 1797) (Lepidoptera: Noctuidae) também é uma das principais pragas da cultura do sorgo, causando desfolha e reduzindo a área foliar para fotossíntese. Devido ao cultivo de milho ou sorgo na segunda safra agrícola (“safrinha”) em sucessão à soja, pragas que anteriormente eram consideradas secundárias têm aumentado a ocorrência em lavouras nos sistemas de plantio direto, como é o caso do percevejo-barriga-verde *Diceraeus melacanthus* (Dallas, 1851) (Hemiptera: Pentatomidae). O percevejo barriga-verde tem o hábito de se alimentar e reproduzir sob a palhada das culturas antecedentes, e causa danos significativos às plantas de milho e sorgo no início do desenvolvimento vegetativo, reduzindo o vigor e além de poder causar a morte das plantas (CONAB, 2020; GASSEN, 1996; CORRÊA-FERRERA; SOSA-GOMÉZ, 2017).

Neste sentido, este trabalho foi dividido em três artigos. O primeiro objetivou avaliar a suscetibilidade do sorgo *bmr*-6 à lagartas de *D. saccharalis* e *S. frugiperda* e se o menor teor de lignina nas plantas favorece ou não a alimentação e desempenho das pragas. O conhecimento dessas informações é de grande importância, uma vez que a redução de lignina na matéria-prima bioenergética poderia causar maior suscetibilidade a insetos-praga pelo fato de esse composto fenólico representar um mecanismo de defesa de plantas a insetos herbívoros

(DOWD et al. 2016; VENDRAMIM and GUZZO 2019). No segundo artigo, o objetivo foi conhecer o potencial de dano da praga na cultura do sorgo em três dos materiais comerciais mais utilizados, bem como se variam quanto aos níveis de resistência para auxiliar no desenvolvimento de estratégias de MIP na cultura do sorgo. E o terceiro artigo, o objetivo foi avaliada a suscetibilidade de 30 híbridos de sorgo granífero a três importantes pragas da cultura, *S. frugiperda*, *D. saccharalis* e *D. melacanthus*.

2 REFERENCIAL TEÓRICO

2.1 A CULTURA DO SORGO E SUAS PRAGAS

O sorgo é considerado uma planta rústica que tem boa adaptação a diferentes condições ambientais, podendo produzir bem em condições que seriam desfavoráveis a maioria dos outros cereais (SILVA et al., 2017). Existem diferentes tipos de sorgo: o granífero, destinado à produção de grãos; o forrageiro, para produção de silagem; o sacarino, para produção de etanol; o sorgo vassoura, utilizado para fabricação de vassouras; e o biomassa, usado para geração de energia em usinas termelétricas (VILELA et al., 2017). Além disso, as plantas e lavouras com as diferentes aptidões supracitadas possuem porte, ciclo de cultivo e tratos culturais diferenciados. Nesse sentido, as infestações de insetos-praga podem ter importâncias distintas dependendo do grupo de sorgo. Também, os genótipos de sorgo dentro de cada grupo podem apresentar diferenças em características bioquímicas, como no teor de açúcares solúveis, lignina e minerais (CHUPIN et al., 2017), e estas características podem afetar a resistência a insetos-praga.

Na fase inicial de desenvolvimento do sorgo, a cultura pode ser atacada por diversas espécies de insetos praga. Entre os mais importantes se destacam os corós (*Phyllophaga* spp., *Stenocrates* spp., *Cyclocephala* spp., *Diloboderus* spp.) (Coleoptera: Scarabaeidae), cupins (*Heterotermes* spp., *Syntermes* spp., *Proconitermes* spp.) (Blatodea: Termitidae), larvas-alfinetes *Diabrotica speciosa* (Germar, 1824) e *Diabrotica viridula* (Fabricius, 1801) (Coleoptera: Chrysomelidae), percevejos-castanhos *Scaptocoris castanea* (Petry, 1830) e *Atarsocoris brachiariae* (Becker, 1996) (Hemiptera: Cydnidae), percevejo-preto *Cyrtomenus mirabilis* (Hemiptera: Cydnidae), lagarta-elasmo *Elasmopalpus lignosellus* (Zeller, 1848) (Lepidoptera: Pyralidae), larva-arame *Conoderus escalaris* (Germar, 1824) (Coleoptera: Elateridae), larva-angorá *Astylus variegatus* (Germar, 1824) (Coleoptera: Dasytidae) e os percevejos-barriga-verde *Dicereaus furcatus* (Fabricius, 1775) e *Dicereaus melacanthus* (Dallas, 1851) (Hemiptera: Pentatomidae) (MENDES et al., 2014).

Na fase vegetativa do sorgo podem-se encontrar os pulgões *Rhopalosiphum maidis* (Fitch, 1856) e *Schizaphis graminum* (Rondani, 1852) (Hemiptera: Aphididae), lagarta-do-cartucho *Spodoptera frugiperda* (J. E. Smith, 1797), curuquerê-dos-capinzais *Mocis latipes* (Guennée, 1852) (Lepidoptera: Noctuidae), e a broca-do-colmo *Diatraea saccharalis* (Lepidoptera: Crambidae).

Por fim, na fase reprodutiva merecem destaque a mosca-do-sorgo *Stenodiplosis* (=*Contarinia*) *sorghicola* (Coquillett) (Diptera: Cecidomyiidae), os percevejos-da-panícula *Leptoglossus zonatus* (Dallas, 1852 (Hemiptera: Coreidae), *Nezara viridula* (Linnaeus, 1758), *Thyanta perditor* (Fabr., 1794) (Hemiptera: Pentatomidae), *Sthenaridea carmelitana* (Carvalho, 1948) (Hemiptera: Miridae), e a lagarta *Helicoverpa zea* (Boddie, 1850) (Lepidoptera: Noctuidae) (WAQUIL; VIANA; CRUZ, 2003).

Na região Sudeste e Centro Oeste do Brasil, geralmente a cultura do sorgo é implantada no período de segunda safra, logo após a colheita de soja precoce. Isto faz com que pragas remanescentes nos restos culturais possam migrar para as culturas do sorgo e do milho, como tem recentemente ocorrido com o percevejo-barriga-verde *D. melacanthus*. Este percevejo causa danos significativos às plantas de milho e sorgo no início do desenvolvimento vegetativo, reduzindo o vigor, promovendo o perfilhamento precoce e pode até matar a planta (WAQUIL; OLIVEIRA, 2009; CORREA-FERRERA et al, 2017).

Na safra 2018/2019, foi observada nos plantios de sorgo, principalmente em sorgo granífero, alta infestação atípica do pulgão da cana-de-açúcar *Melanaphis sacchari* (Zethner, 1897) (Hemiptera: Aphididae). Este pulgão é considerado como uma forte ameaça à cultura do sorgo não só no Brasil, como nos Estados Unidos desde 2013 (PAUDYAL et al., 2019). Entre todas as pragas do sorgo, a broca-do-colmo *D. saccharalis* é considerada a mais importante para o sorgo sacarino por causar injúrias na parte econômica da planta, que é o colmo. Juntamente com *S. frugiperda*, *D. melacanthus*, *S. graminum*, e mais recentemente *M. sacchari* são consideradas as pragas-chave da cultura do sorgo, ou seja, as que demandam mais atenção no monitoramento e controle.

O ataque de pragas pode ser um importante fator na perda de produtividade do sorgo, reduzindo a expressão do seu potencial. Dessa forma, torna-se muito importante o uso de diferentes táticas de controle no manejo integrado das pragas dessa cultura (MENDES et al., 2014). Diante disso, selecionar genótipos resistentes ou tolerantes às principais pragas do sorgo é de suma importância para programas de melhoramento genético e de MIP.

2.2 *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera: Noctuidae)

A lagarta-do-cartucho *S. frugiperda* possui distribuição geográfica generalizada, causando danos durante, praticamente, em todas as fases de desenvolvimento do milho (DEQUECH et al., 2013). Em geral, o sorgo é mais resistente que o milho à lagarta-do-cartucho. Entretanto, há cultivares de sorgo que são tão suscetíveis a essa espécie quanto o milho.

Condições tropicais de cultivo aliadas as características dessa espécie como polifagia e alta capacidade de reprodução, dispersão e migração dos adultos (NAGOSHI; MEAGHER, 2008), favorecem a ocorrência de gerações sobrepostas ao longo do ano, levando a graves infestações em safras agrícolas (BERNARDI et al., 2015).

O adulto de *S. frugiperda* é uma mariposa com aproximadamente 3,5 cm de comprimento, coloração pardo-escura nas asas anteriores e branco-acinzentadas nas posteriores, com longevidade de aproximadamente 15 dias (SANTOS et al., 2004). As posturas são feitas em massa, com média de 150 ovos. O período para eclosão das larvas é de aproximadamente três dias.

As larvas recém-eclodidas alimentam-se do próprio córion dos ovos e, posteriormente das folhas da planta, provocando o sintoma conhecido como “folhas raspadas”, o que é um sintoma da presença da lagarta na cultura. As lagartas passam por cinco ou seis estádios larvais, atingindo 40 a 50 mm de comprimento e 2,7 a 2,78 mm de largura da cápsula cefálica. À medida que as lagartas crescem, começam a fazer orifícios nas folhas, podendo causar severas injúrias às plantas (CRUZ; ALVARENGA; FIGUEIREDO, 1995). A duração da fase larval é de 12 a 30 dias. Após este período as lagartas se direcionam para o solo onde passarão à fase de pupa, que dura entre 10 a 12 dias. O ciclo biológico desse inseto em plantas de milho completa-se em 25 dias à temperatura de 25ºC, aumentando o número de dias quando as temperaturas estão mais baixas (BUSATO; GRUTZMACHER; GARCIA, 2005a; BUSATO; GRUTZMACHER; GARCIA, 2005b).

Os primeiros trabalhos que tentaram identificar fontes de resistência do sorgo à lagarta-do-cartucho foram realizados por McMillian & Starks (1967) nos EUA e por Lucena (1978) no Brasil. Mesmo considerando o pequeno número de genótipos avaliados foi possível identificar tipos contrastantes como AF-28 (menor índice de infestação) e EA 261 (menor consumo de biomassa). Entre 20 variedades de sorgo sacarino, foi observada uma redução no consumo das lagartas de 44% da área foliar da variedade Honey quando comparada à variedade Dale (WAQUIL; SANTOS, 1990). A avaliação de 18 acessos de sorgo selecionados, previamente, para resistência à lagarta-do-cartucho, de 326 acessos do Banco Ativo de Germoplasma da Embrapa Milho e Sorgo, Santos et al. (1992) identificaram como resistentes: AF 28; MN 1533; IS 5831, que causaram 67% de mortalidade de larvas, e Tx 7078 e BTx 611 wx, que apresentaram menor área foliar consumida (SANTOS et al., 2005).

Como a distribuição da infestação natural no campo é muito irregular a seleção de híbridos sob infestação natural fica prejudicada. Desta forma, como a lagarta-do-cartucho pode ser criada em laboratório, os trabalhos mais recentes têm sido conduzidos com infestação artificial, que podem ser conduzidos em laboratório, casa-de-vegetação ou no campo (neste caso já ocorre a infestação natural). Para avaliar a resistência à desfolha por *S. frugiperda* existem escalas de notas de injúria, de modo que de acordo com a intensidade da injúria maior será a nota atribuída. Entre as escalas de injúria no milho destacam-se a de 0-5 desenvolvida por Carvalho (1970) e a de 1-9 desenvolvida por Davis (1992). Gonçalves et al. (2011) avaliaram através de escala de notas (0-5) genótipos de sorgo sacarino em casa-de-vegetação aos 14 dias após a infestação das lagartas. Segundo os autores, o índice de adaptação das lagartas aos genótipos de sorgo sacarino seguiu a seguinte ordem decrescente (do mais adaptável aos menos adequados à lagarta-do-cartucho): BR505, CMSX5634, BR501, CMSX5642 e CMSX5630.

Na avaliação da adubação nitrogenada em sorgo, López et al. (2000) não verificaram correlação significativa entre parâmetros de desenvolvimento da lagarta-do-cartucho e a concentração total de nitrogênio nas plantas. Ao avaliar três cultivares comerciais de sorgo quanto à infestação de *S. frugiperda*. Cortez; Waquil (1997) encontraram grande variação nos parâmetros avaliados, sugerindo que haja constante avaliação de genótipos com potencial para se utilizar a resistência do sorgo no MIP.

2.3 *Diatraea saccharalis* (Fabricius, 1794) (Lepidoptera: Crambidae)

A broca-do-colmo ou broca-da-cana-de-açúcar *D. saccharalis* é uma praga primária para a cana-de-açúcar, mas por ser polífaga se alimenta de outras culturas e tem causado perdas significativa no milho, trigo, sorgo e milheto (MENDES et al., 2014). Pelo comportamento alimentar formando galerias, a praga se encontra protegida, dificultando o controle químico. Dessa forma, a utilização de genótipos resistentes e tolerantes são as táticas de controle mais promissoras para o manejo de *D. saccharalis* na cultura do sorgo (MENDES et al., 2014; SANTOS; MIHSFELDT, 2014). Na cultura do sorgo ela pode danificar tanto o colmo como o pedúnculo da panícula. Quando a injúria é no colmo, causa quebramento e redução na produção e quando é no pedúculo causas morte da panícula provocando o sintoma de panícula-branca, com 100% de perda da planta atacada no caso do sorgo granífero.

As galerias provocadas pelas lagartas de *D. saccharalis* deixam as plantas mais vulneráveis à queda pela ação do vento, o que é um prejuízo indireto muito importante: o colmo fica enfraquecido, podendo quebrar ou tombar. O ataque da broca-do-colmo causa podridão por favorecer a entrada de microrganismos, causando o acúmulo de micotoxinas, morte da gema apical, redução do fluxo de seiva, encurtamento dos entrenós dos colmos e acamamento, debilitando a planta de forma geral (MENDES et al., 2014; SILVA et al., 2014).

O adulto é uma mariposa de coloração amarelo-palha, de 20 mm de envergadura. Os ovos têm aspecto de escamas; inicialmente possuem coloração amarelo-claro, alaranjado e vão escurecendo quando perto da eclosão da lagarta. Os ovos são colocados nas folhas e a eclosão ocorre entre quatro e nove dias. Inicialmente, as lagartas se alimentam das folhas, passam para a bainha e depois se direcionam para o colmo, fazendo galerias ascendentes e originando um orifício por onde a mariposa emerge, que pode variar de nove a 14 dias (MENDES et al., 2014).

A maioria dos trabalhos com avaliação de genótipos de sorgo para a resistência a *D. saccharalis* e outros lepidópteros no país foram realizados há mais de 15 anos. Dentre esses trabalhos, Bortoli et al. (2005) ao avaliarem o efeito da adubação em uma cultivar de sorgo no desenvolvimento de *D. saccahralis* observaram que as menores porcentagens de injúria foram verificadas com as menores doses de nitrogênio e maiores doses de potássio.

Normalmente, as avaliações são baseadas na taxa de plantas com panículas mortas, nos índices de infestação (% plantas infestadas) e de intensidade de infestação (% de internódios danificados). Para se avaliar esses índices, deve-se abrir o colmo longitudinalmente e examinar. Pode-se utilizar também uma escala visual de notas (variando de 0 a 9 com base na área foliar consumida para se estimar as injúrias causadas pelas lagartas nas folhas. Muitas fontes demonstraram resistência cruzada a diferentes espécies de brocas, como os IS 1055 (BP53), IS 1044, IS 2123, IS 2195, IS 2205, IS 5469 e IS 18551.

A variedade Brandes, AF 28 e SC 3541 foram consideradas as mais resistentes à broca-do-colmo (Waquil et al., 1980; Boiça Jr.; Lara, 1983; Lara et al., 1997). Entre as cultivares comerciais, os resultados mostraram que o BR 304 e o CMSXS9701 apresentaram os menores índices de infestação enquanto que Z 732 e Esmeralda destacaram-se com os menores índices de intensidade de infestação (WAQUIL et al., 2001). Os autores encontraram alta variabilidade genética entre os materiais comerciais, e perdas significativas na produtividade podem ocorrer em todos os híbridos avaliados. Por outro lado, a variabilidade genética observada entre as linhagens de sorgo indica grande potencial para a seleção de cultivares resistentes nos programas de melhoramento (WAQUIL et al., 2001).

Lara et al. (1979) encontraram resistência em dois genótipos de sorgo entre 89 avaliados para *D. saccharalis*, e após quase duas décadas também foram encontrados dois genótipos com resistência induzida indireta (denominada pelo autor de resistência extrínseca) a *D. saccharalis*, considerando o maior parasitoidismo por *Cotesia flavipes* (Cameron, 1891) (Hymenoptera: Braconidae) (LARA et al., 1997). Genótipos de sorgo, 10 híbridos de sorgo sacarino e 16 de sorgo biomassa foram avaliados em relação à resistência a *D. saccharalis*, com destaque para o genótipo CMSXS647 pelas características altura de plantas, nível de infestação, tamanho de galerias e teor de sólidos solúveis entre os sacarinos, enquanto que entre os genótipos de sorgo biomassa, destacaram CMSXS7030, CMSXS7012 e CMSXS7028, os quais apresentaram características desejáveis para nível de infestação, altura de plantas e número de compostos lignocelulósicos (ARAÚJO et al., 2019). Mais tarbalhos de levantamento de genótipos e híbridos resistentes ou tolerantes a esta praga são necessários.

2.4 *Diceraeus melacanthus* (Dallas, 1851) (Hemiptera: Pentatomidae)

Na região Sudeste e Centro Oeste do Brasil, geralmente a cultura do sorgo é implantada no período de segunda safra, logo após a colheita de soja precoce. Nesse contexto, pragas que anteriormente eram consideradas secundárias vêm recebendo grande atenção pelo elevado crescimento populacional nos sistemas de cultivo direto. Isto faz com que pragas remanescentes nos restos desta cultura possam migrar para as culturas do sorgo e do milho, como é o que tem acontecido nas últimas safras com o percevejo-barriga-verde *D. melacanthus*. Este percevejo causa injúrias significativas às plantas de milho e sorgo no início do desenvolvimento vegetativo, reduzindo o vigor, promovendo o perfilhamento precoce e pode até matar a planta (WAQUIL; OLIVEIRA, 2009; CORREA-FERRERA et al, 2017).

O percevejo barriga-verde tem o hábito de se alimentar e reproduzir sob a palhada das culturas antecedentes, e causa injúrias significativas às plantas de milho e sorgo no início do desenvolvimento vegetativo, reduzindo o vigor e além de poder causar a morte das plantas (GASSEN, 1996; CORRÊA-FERRERA; SOSA-GOMÉZ, 2017). Ao se alimentar, normalmente se posiciona na base do colmo da planta hospedeira com a cabeça voltada para baixo, e introduz os estiletes para sugar a seiva do floema, cuja sucção é facilitada pela injeção de enzimas salivares que são tóxicas às plantas, o que prejudica seu desenvolvimento (BIANCO, 2004; GRIGOLLI et al., 2016).

A planta é mais suscetível às injúrias causadas por *D. melacanthus* nos primeiros dias após a emergência das plantas (BIANCO, 2004), provavelmente por ser a fase mais sensível que se define o potencial produtivo da cultura. Nesse sentido a intensidade do dano pode variar com o número de percevejos na lavoura também com a escolha do híbrido e do manejo adotado. Estudos com *D. melacanthus* já foram propostos para cultura do milho, mas na cultura do sorgo ainda são insipientes (BIANCO, 2004; ROZA-GOMÉZ et al., 2011; DUARTE et al., 2015; CRUZ et al., 2016; FERNANDE et al., 2020; BUENO et al., 2021).

2.5 Sorgo biomassa (*bmr*)

O sorgo biomassa apresenta rápido crescimento e alta produção, podendo atingir 150 toneladas ha^{-1}. As plantas podem chegar até 6 m de altura em 180 dias (PARRELLA, 2013). Além disso, possui cultivo totalmente mecanizado e poder calorífero parecido com o da cana-de-açúcar, eucalipto e capim-elefante (MAY, 2013). O sorgo biomassa pode ser utilizado em usinas termelétricas e em indústrias que utilizam caldeiras para geração de energia para consumo próprio, visando ao fornecimento de matéria-prima para cogeração de energia e/ou produção de etanol de segunda geração. Por ser uma cultura relativamente nova para essa finalidade, pesquisas com os mais variados propósitos devem ser realizadas, e dentre elas, cabe à investigação das defesas das plantas de sorgo biomassa ao ataque de insetos-praga (MAY, 2013; PARRELLA, 2013).

No âmbito de geração de energia, biomassa é qualquer produto ou coproduto de um recurso renovável procedente de matéria orgânica basicamente formada por hidratos de carbono e que pode ser utilizada na produção de energia (CCEE, 2021). A parede das células vegetais é composta por três grandes polímeros: a celulose, que constitui a maior proporção, a hemicelulose, que é a segunda mais abundante, e a lignina. A celulose é uma cadeia de moléculas de glicose bem organizada, enquanto a hemicelulose não apresenta uma padronização em sua estrutura; existem outros açúcares em sua constituição além da glicose, como manose, xilose, arabinose e galactose, além de alguns ácidos (RUBIN, 2008). A lignina é formada por três componentes fenólicos principais: álcool p-coumaryl, álcool coniferílico e álcool sinapílico; são polímeros aromáticos que variam em suas ramificações e se condensam em diferentes estruturas. Os três grandes polímeros presentes na parede celular das plantas são organizados em microfibrilas que dão estabilidade estrutural à parede celular (RUBIN, 2008).

O colmo das plantas também é constituído de celulose, hemicelulose e lignina, além de cinzas que é a parte mineral, que dá sustentação ao colmo (SANTOS et al., 2011). Como o sorgo biomassa possui alto teor de lignina, pode ser utilizado para cogeração de energia, pois a lignina aumenta o poder calorífero necessário para a queima. Dentro da categoria biomassa, existe o sorgo *bmr* (*brown midrib*), que é um genótipo mutante caracterizado pela presença de nervura das folhas com coloração amarronzada. Essa mutação foi primeiramente observada naturalmente em plantas de milho (JORGENSON, 1931), e desde então foi induzida no sorgo através de tratamento químico com o uso de metano sulfonato de etila. A mutação faz com que o teor de lignina na planta de sorgo reduza substancialmente (XIN et al., 2008). Dessa forma, sua utilização torna-se ideal para a produção de etanol de segunda geração, em que a lignina é um impedimento para a sacarificação e fermentação da biomassa em etanol (DIEN et al., 2009). Além disso, pode proporcionar melhor digestibilidade ao gado (CHERNEY et al., 1991).

Para produção de etanol de segunda geração no Brasil, a matéria-prima largamente utilizada é o bagaço de cana-de-açúcar (CCEE, 2021). No entanto, apesar da sacarídea estar muito bem estabelecida, são necessárias mais alternativas para compor a matriz energética nacional. O sorgo biomassa é uma matéria-prima lignocelulósica promissora por ser uma cultura rústica, ter um sistema de produção já bem conhecido, apresentar adaptação a diferentes condições ambientais e tolerar deficiência hídrica, o que é uma vantagem em um cenário que demanda economia de água (SILVA et al., 2017). Com a escassez de chuvas, há redução na oferta de energia proveniente das hidrelétricas, demandando geração térmica por biomassa, cenário ideal para a participação do sorgo biomassa (CCEE, 2021). O sorgo biomassa *bmr* tem importância também para alimentação animal, o valor nutritivo é maior, o menor teor de lignina facilita a digestibilidade (EBLING & KUNG Jr. 2004). Com a redução da lignina e aumento da digestibilidade da FDN é um parâmetro importante para qualidade da forragem, com a melhor digestão da parte fibrosa, reduz o efeito do enchimento do rúmen e aumenta o consumo de matéria seca (OBA & ALLEN, 1999).

Apesar da rusticidade do sorgo, o ataque de insetos-praga representa um problema à cultura. A broca-do-colmo *D. saccharalis* é uma das principais pragas da cultura do sorgo, cujo maior prejuízo é deixar o colmo frágil e suscetível ao tombamento, reduzindo o fluxo de seiva na planta, entre outros problemas (MENDES et al., 2014; SILVA et al., 2014). Portanto, como o sorgo biomassa é muito volumoso, com porte de 5-6 m de altura, se houver infestação da broca-do-colmo a probabilidade de tombamento será ainda maior. Além disso, pelo fato de o sorgo *bmr* ter menor teor de lignina, é naturalmente mais suscetível ao tombamento devido à maior fragilidade estrutural. (PARRELLA, 2013). Portanto, torna-se necessário verificar se o menor teor de lignina nas plantas favorece ou não a oviposição, alimentação e desenvolvimento das pragas, uma vez que a redução de lignina na matéria-prima bioenergética poderia causar suscetibilidade a insetos-pragas pelo fato de esse composto fenólico representar um mecanismo de defesa de plantas a herbívoros (DOWD; FUNNELL-HARRIS; SATTLER, 2016; VENDRAMIM; GUZZO, 2019).

2.6 Sorgo granífero

O sorgo granífero é uma importante cultura de cereal usado como grão e pode substituir o milho em rações para alimentação animal, como para alimentação humana em regiões da África e Ásia, além de ser promissor para alimentação humana em função de ser rico em compostos bioativos, funcionais e não conter glúten (WAQUIL, et al., 2003; FAO, 1995; MARTINO et al., 2014). Diante disso, tem crescido a demanda por produtos à base de sorgo como massas para pães, macarrão, barras de cereais, “snacks”, bolos, biscoitos e cerveja; todos estes produtos apresentam alto valor agregado pelos benefícios à saúde humana como alternativa aos cereais convencionais (MARTINO et al., 2014; ABDELGHAFOR et al., 2011; BURDETE et al., 2010; CARDOSO et al., 2014). O sorgo granífero cotribui para uma oferta de menor custo de grãos em épocas de menor pluviosidade e possui baixa suscetibilidade a micotoxinas que é comum no milho e faz com que seja um cereal seguro para composição de rações de modo geral (MENEZES et al,.2015).

Na safra 2020 no País foram produzidas quase 2,5 milhões de toneladas de grãos de sorgo, com destaque para o estado de Goiás que representa mais de 40% da produção nacional, seguido por Minas Gerais (IBGE, 2020). O sorgo geralmente é plantado na segunda safra em sucessão a cultura da soja. O plantio varia entre fevereiro e abril dependendo da região do país. O Centro-Oeste e Sudeste são os principais responsáveis pela produção de sorgo no Brasil. O levantamento de produção estimada é de produzir 1,29 milhão de toneladas para safra 2020/2021. O Estado de Goiás é o maior produtor de sorgo do país representando 49,7% da produção nacional. A expectativa é de aumento de 17,5% na produção, em comparação com a safra (CONAB, 2021). No ranking mundial de produção de sorgo, os Estados Unidos é o principal produtor, seguido de países da África, México, Argentina, Brasil, Índia, Pasquitão, China, Austrália e União Européia (USDA, 2021).

2.7 Resistência de plantas a insetos

A resistência de plantas é a soma relativa de qualidades hereditárias possuídas pela planta, as quais influenciam o resultado do grau de dano causado por um inseto (PAINTER, 1951). Assim, planta resistente pode ser definida como aquela que, devido a sua constituição genotípica, é menos danificada que outras, consideradas suscetíveis, em igualdade de condições (ROSSETTO, 1973).

Alguns princípios básicos da resistência de plantas a insetos devem ser observados. A resistência é relativa, o que implica na comparação de duas ou mais plantas. Dessa forma, quando se diz que uma planta é resistente a um determinado inseto significa que ela manisfesta esta resistência em relação a outras plantas. A resistência é hereditária, isto é, trata-se de um caráter genético, de modo que as progênies de uma planta resistente devem expressar a resistência da mesma forma quando testadas nas condições em que a resistência se revelou. A resistência é específica. Ou seja, pode ser resistente a uma espécie de inseto e suscetível a uma outra espécie. Também apresenta plasticidade fenotípica de acordo com a interação do genótipo x ambiente, podendo alterar o fenótipo dependendo das condições ambientais. Isto pode implicar, por exemplo, no nível expresso de resistência. Além disso, é necessário que haja repetibilidade das respostas. Ou seja, todas as vezes que se testar a variedade resistente em comparação com as outras variedades testadas, aquela característica deverá se manifestar (LARA, 1991; BALDIN et al., 2019).

2.7.1 Classificação da resistência de plantas a inseto

Quanto às formas de expressão das características de resistência, podem ser constitutivas e induzidas. A resistência constitutiva é de modo geral constantemente expressa na planta, e assim os genes que participam da codificação de substâncias químicas, características físicas e morfológicas são expressos em geral durante todos os estádios de desenvolvimento da planta (SCHOONHOVEN et al., 2005). Por outro lado, a resistência induzida ocorre após o reconhecimento de algum estímulo ou fator de estresse, com a ação de elicitores como o ácido jasmônico e salicílico após a ocorrência de herbivoria ou oviposição, infecção por patógenos ou outro tipo de estresse biótico ou abiótico (ZARATE et al., 2007). Através do reconhecimento inicial destes elicitores por receptores de reconhecimento de padrões moleculares, as plantas apresentarão uma resposta induzida de defesa, seja aumentando quantitativamente a produção de tricomas, enzimas antioxidantes e de defesa, compostos químicos tóxicos ou anti-nutricionais para o inseto, quanto expressão qualitativa dessas e outras características (VENDRAMIM et al., 2019).

Além do modo de expressão dos genes e características de resistência, esta pode ser classificada como direta, como por exemplo, espinhos, tricomas, formato, espessura da parede celular, velocidade de crescimento celular, dureza dos tecidos atacados, incrustação de minerais como silício na cutícula, presença de cera na superfície da folha, aumento da síntese de algum composto secundário ou enzimas oxidantes e de defesa que têm efeitos diretamente no inseto fitófago (HOFFMAN-CAMPOS; GRAÇA, 2019; VENDRAMIM et al., 2019).

Quando a planta é induzida, como por exemplo, pela herbivoria de insetos, desencadeia mudanças na preferência, desempenho ou reprodução do inseto diante da planta hospedeira que vai fazer com que se alimente menos ou tenha uma redução de peso, alteração no desenvolvimento, e por fim, taxa de sobrevivência e oviposição, resultando crescimento populacional (SCHOLZ et al., 2015). A resistência indireta compreende a produção de compostos orgânicos voláteis que a planta libera e que atraem inimigos naturais dos herbívoros que estão se alimentando daquela planta (SCHOONHOVEN et al., 2005). As plantas liberam voláteis para comunicação entre elas e os herbívoros, orientando o comportamento de busca de inimigos naturais como predadores e parasitoides, atraindo ou repelindo para a aceitação ou não do hospedeiro, podendo afetá-los de diferentes formas, tanto na parte aérea quanto subterránea (STOUT, 2013). Existem também estruturas morfológicas produzidas de forma induzida nas plantas como os nectários extraflorais presentes em folhas e caules que podem ser utilizados como fonte de alimento para predadores e parasitoides, e as domácias que são estruturas presentes em algumas plantas como cavidades ou tufos de pelos que servem como abrigo e alimento para os inimigos naturais (SILVA; PANIZZI, 2019).

Do ponto de vista genético, a resistência pode ser: monogênica (um lócus), oligogênica (poucos loci) ou poligênica (muitos loci). A interação pode ser intra-alélica – a expressão da resistência pode ser recessiva; dominante ou com dominância incompleta ou inter-alélica – a expressão da resistência pode depender de dois ou mais genes com ação complementar (sendo um único insuficiente); pode ser aditiva (dois genes não-alélicos afetam a mesma característica) e epistática (um gene inibe a ação de outro) (HSIEH & PI, 1982).

Em relação à resposta entre as populações de plantas e a espécie da praga, existe a resistência horizontal que é quando a planta resistente expressa o mesmo nível de resistência, contra todos os biótipos do inseto-praga (raças semelhantes morfologicamente, mas com respostas diferenciadas em função da variação na população da planta) e vertical, quando a resistência é específica para cada biótipo do inseto-praga (KOGAN 1975; LARA 1991; BALDIN et al. 2019). Os fatores ambientais também podem afetar a expressão da resistência como a temperatura, luminosidade, umidade relativa, estádio de desenvolvimento da planta ou de seus tecidos, estado nutricional da planta e aplicação de defensivos e reguladores de crescimento (LARA et al., 1991).

2.7.2 Antixenose

Antixenose é o tipo de resistência responsável pela não preferência do inseto para alimentar, ovipositar ou se abrigar em um determinado fenótipo de planta (KOGAN; ORTMAN, 1978). Os insetos possuem diversificação na preferência porque eles utilizam estímulos fornecidos pelas plantas, os quais são responsáveis por desencadear respostas em favor ou contrária à planta hospedeira. Os semioquímicos são estímulos químicos que regulam ou mediam a seleção hospedeira por insetos e podem ser subdivididos em dois grandes grupos: os aleloquímicos que são interespecíficos (comunicação entre individuos de espécies diferentes) e os feromônios que são intraespecíficos (comunicação entre indivíduos de mesma espécie).

Em termos da inter-relação inseto-planta, a importância deve ser atribuída ao grupo dos aleloquímicos, pois são substâncias que traduzem um significado comportamental e biológico a organismos pertencentes a espécies diferentes (BALDIN et al.,2019). Os aleloquímicos subdividem-se em cairomônios, alomônios, sinomônios e apneumônios. Cairomônios são as substâncias que, quando entram em contato com o indivíduo de outras espécies, como insetos, causam uma reação comportamental ou fisiológica favorável ao receptor e não ao emissor. Por outro lado, alomônios proporcionam o inverso da resposta, ou seja, é desfavorável ao receptor, mas não ao emissor. Sinomônios são substâncias que em contato com o indivíduo de outra espécie despertam uma reação comportamental ou fisiológica favorável a ambos, tanto ao emissor quanto receptor. São exemplos relacionados à resistência indireta, pois favorecem os inimigos naturais, atraindo-os, e também às plantas devido ao controle de pragas realizados pelos inimigos naturais atraídos à planta. Por fim, apneumônios são compostos químicos que são emitidos por matéria morta e que resultam em uma reação comportamental ou fisiológica favorável ao receptor em um organismo que esteja dentro ou sobre o material emissor (BALDIN et al., 2019; SILVA; PANIZZI, 2019).

Com relação às respostas desencadeadas pelos cairomônios das plantas aos insetos, podem ser atraentes, atuando de forma que induz o inseto a se movimentar em direção à planta; arrestante, quando induz o inseto a se agregar à planta ou diminuir a locomoção para que eles avaliem melhor a planta a curta distância; excitante ou incitante, quando leva o inseto a provar a planta, ou seja, induz a picada ou “mordida” inicial, à penetração do ovipositor; e estimulante de alimentação ou oviposição, quando induz o inseto a continuar se alimentando ou ovipositando em uma planta adequada (BALDIN et al., 2019).

Os alomônios presentes nas plantas provocam reações inversas às provocadas pelos cairomônios, isto é, são desfavoráveis aos insetos e favoráveis às plantas. Eles podem ser classificados como repelentes, quando induzem o inseto a movimentar-se em direção oposta à planta; estimulante de locomoção, quando induz o inseto a se afastar mais rapidamente da planta; supressante ou supressor, quando inibe ou evita o início da alimentação (picada ou "mordida"), a penetração inicial ou a oviposição (inibição de oviposição, segundo alguns autores); e deterrente, quando impede a continuidade da alimentação ou oviposição. A resposta final do inseto depende do balanço entre os estímulos positivos e negativos como, por exemplo, se o estímulo negativo repelente sobrepor ao atraente, o inseto não se orientará em direção à planta e vice-versa (WHITTAKER; FEENEY, 1971).

2.7.3 **Antibiose**

Antibiose é o tipo de resistência preponderante nas plantas quando o inseto se alimenta e ela exerce efeito adverso sobre a sua biologia, afetando direta ou indiretamente seu potencial biótico (LARA, 1991; BALDIN et al., 2019). Os efeitos negativos nos insetos podem ser devido às toxinas que as plantas apresentam como, por exemplo, a presença de inibidores de crescimento ou reprodução, nutrição inapropriada que causam mortalidade nas fases de larva, ninfa, pupa ou na muda, redução do tamanho e peso dos indivíduos e da fecundidade, alteração da proporção sexual e da longevidade, entre outros parâmetros biológicos (BALDIN et al., 2019).

O efeito adverso que a planta exerce sobre parâmetros da biologia do inseto e que faz com que a planta apresente antibiose pode ser devido à presença de compostos antibióticos que atuam na fisiologia e biologia do inseto, e podem ser: metabólitos tóxicos que atuam produzindo intoxicação crônica ou aguda nos insetos, como alcaloides, glicosídeos cianogênicos e cardíacos, quinonas, etc (BALDIN et al., 2019; VENDRAMIM, et al., 2019; antimetabólitos que têm a propriedade de tornar os nutrientes essenciais indisponíveis aos insetos ou atuar como inibidores enzimáticos; enzimas que atuam no processo de utilização do alimento, inibindo ou reduzindo o processo normal da digestão; fitoesteroides como por exemplo alguns triterpenos, saponinas e tetranortriterpenoides, como a azadiractina, que podem agir no inseto como seu próprio hormônio juvenil, ou como hormônio da ecdise, que induzem a metamorfose precoce, esterilidade e diapausa devido ao desequilíbrio hormonal (VENDRAMIM et al., 2019).

2.7.4 Tolerância

Tolerância ocorre quando a planta resistente mesmo atacada da mesma forma que as outras plantas suscetíveis, ela consegue se compensar, crescer e produzir normalmente. A tolerância é caracterizada pela presença de atributos que não interferem sobre o inseto nem sua biologia e nem no seu comportamento, sendo uma característica que faz com que da planta sofra menos com o ataque do que outras em igualdade de condições. Muitas plantas podem suportar uma determinada relação de injúrias sem ter perda de rendimento (PETERSON et al., 2017; ERB, 2018; SPEROTTO et al., 2018). Desta forma, insetos-praga não são selecionados quanto à resistência devido a ausência de pressão de seleção imposta por plantas tolerantes (KOCH et al., 2019).

A tolerância, apesar da sua importância, tem sido menos utilizada e estudada do que a antibiose e antixenose. Isto pode ser devido a vários fatores como, por exemplo, a grande influência ambiental tornando mais difícil a identificação e seleção de plantas resistentes (STOUT, 2013). Também, os mecanismos da tolerância ainda são pouco compreendidos, complexos e de herança poligência, tornando o processo mais lento. Por outro lado, o interesse das empresas e dos produtores que utilizam as variedades resistentes é reduzir a incidência da praga ao invés de gerenciar a biologia das plantas (PETERSON et al., 2017; ERB, 2018; SPEROTTO et al., 2018). E mesmo que os insetos não tenham alterações biológicas e/ou comportamentais, o entendimento básico de como as plantas lidam com a herbivoria, e a identificação de genótipos tolerantes nas principais culturas podem ter um grande impacto no manejo de pragas e rendimentos de produção.

Lembrando que a resposta das plantas à injúria da intensidade, do tempo, do tipo e da parte da planta que foi injuriada e as interações com fatores ambientais (PETERSON; HIGLEY, 2001). A tolerância de plantas a insetos sugadores está principalmente associada a mecanismos moleculares como desintoxicação e alterações na atividade fotossintética, enquanto os mecanismos de tolerância em resposta a insetos mastigadores são geralmente descritos por sobrecompensação através da produção de novos tecidos, realocação de recursos e mudança na arquitetura da planta (TRUMBLE et al., 1993; STOWE et al., 2000; KRIMMEL; PEARSE, 2016).

Peterson et al. (2017) lista três fatores que restringem o desenvolvimento de conhecimentos sobre a tolerância: falta de técnicas adequadas para identificar e incorporar a tolerância para as culturas; a capacidade de cultivares tolerantes servirem como reservatórios para vetores de vírus, por exemplo, e a falta de informações básicas sobre a herança da tolerância. Para isto, devem-se realizar pesquisas básicas sobre os mecanismos fisiológicos e bioquímicos de tolerância, a qual deve envolver pesquisa interdisciplinar entre biólogos, ecologistas, químicos, biologia molecular, melhoristas de plantas entomologistas para utilizar cada vez mais esta importante ferramenta no MIP.

3 CONCLUSÃO

Concui-se que devdo a importancia da cultura do sorgo, é recomendado integrar o máximo possível de estratégias de manejo de pragas, intensificando a necessidade de buscar táticas eficientes de manejo, como por exemplo, a resistência de plantas. Diante de todas as ferramentas disponíveis para trabalhar com resistência de plantas, surge a necessidade de mais estudos em relação a resistência do sorgo às suas principais pragas. Devido ao tempo em que os principais trabalhos foram realizados com resistência de sorgoe, principalmente, apenas com sorgo granífero, aliado à falta de trabalhos com sorgo de diferentes categorias, deve-se diante das novas técnicas e perspectivas de pesquisa em resistência de plantas a insetos, juntamente com o crescimento da importância do sorgo no país, realizar mais estudos em programas de melhoramento de sorgo, compatibilizando a maior produtividade e a resistência às principais pragas.

REFERÊNCIAS

ABDELGHAFOR, R. et al. Quality of bread from composite flour of sorghum and hard white winter wheat**. Advance Journal of Food Science and Technology**, v. 3, n. 1, p. 9-15, 2011.

ARAÚJO, O. G. et al. Resistance of bioenergy sorghum to *Diatraea saccharalis* (Lepidoptera: Crambidae). **Bioscience Journal**, v. 35, n. 4, p. 1022-1032, 2019.

BALDIN, E. L. L.; BENTIVENHA, J. P. F. **Fatores que afetam a expressão da resistência**. In: BALDIN, E. L. L.; VENDRAMIM, J. D. LOURENÇÃO, A. L. (eds). Resistência de plantas a insetos- Fundamentos e Aplicações. Piracicaba, São Paulo, Brasil: Fealq, 2019. p. 323-356.

BASTOS, C. S. et al. **Resistência de plantas a insetos: contextualização e inserção no MIP**. In: VISOTTO, L. E. et al. Avanços tecnológicos aplicados à pesquisa na produção vegetal. Editora Suprema, Embrapa Hortaliças, Brasília, 2015. p. 31-72.

BERNARDI, O. et al. Frequency of resistance to Vip3Aa20 toxin from *Bacillus thuringiensis* in *Spodoptera frugiperda* (Lepidoptera: Noctuidae) populations in Brazil. **Crop Protection**, Guildford, v. 76, p. 7-14, 2015.

BIANCO, R. Nível de dano e período crítico do milho ao ataque do percevejo barriga verde (*Dichelops melacanthus*). In: Congresso nacional de milho e sorgo, 25.; Simpósio brasileiro sobre a lagarta-do-cartucho, *Spodoptera frugiperda*, 1., 2004, Cuiabá. Resumos... Sete Lagoas: ABMS: Embrapa Milho e Sorgo: Empaer, 2004. p. 172.

BOIÇA JÚNIOR, A. L.; LARA, F. M. Avaliação da resistência de genótipos de *Sorghum bicolor* (L.) Moench a *Diatraea saccharalis* (Fabricius, 1794) (Lepidoptera-Pyralidae) e determinação dos tipos envolvidos. **Anais da Sociedade Entomológica do Brasil**, Londrina, v. 12, p. 261-272, 1983.

BORTOLI, S. A. et al. Biological aspects and damage of *Diatraea saccharalis* (Lepidoptera: Pyralidae) in sorghum, under different doses of nitrogen and potassium. **Ciência e Agrotecnologia**, Lavras, v. 29, n. 2, p.267-273, 2005.

BUENO, N. M. et al. Characterization of Antixenosis and Antibiosis of Corn Genotypes to *Dichelops melacanthus* Dallas (Hemiptera: Pentatomidae). Gesunde Pflanzen, Berlin, v. 73, p. 67–76, 2021.

BURDETTE, A. et al. Anti-inflammatory activity of select sorghum (*Sorghum bicolor*) brans. **Journal of Medicinal Food**, v. 13, n. 4, p. 1-9, 2010.

BUSATO, G. R.; GRUTZMACHER, A. D.; GARCIA, M. S. Biologia comparada de populações de *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) em folhas de milho e arroz. **Neotropical Entomology**, Londrina, v. 34, n. 5, 2005a.

BUSATO, G. R.; GRUTZMACHER, A. D.; GARCIA, M. S. Exigências térmicas e estimativa do número de gerações dos biótipos ‘milho’ e ‘arroz’ de *Spodoptera frigiperda*. **Pesquisa Agropecuária Brasileira**, Brasília, v. 40, n. 4, 2005b.

CARDOSO, L. M. et al. Sorghum (*Sorghum bicolor* L.): nutrients, bioactive compounds and potential impact on the human health. **Critical Reviews in Food Science and Nutrition**, v. 57, n. 2, p. 372-390, 2014.

CARVALHO, R.P.L. Danos, flutuação da população, controle e comportamento de *Spodoptera frugiperda* (J.E. Smith, 1797) e susceptibilidade de diferentes genótipos de milho, em condições de campo. 1970. 170f. Tese (Doutorado em Entomologia) – Esalq/USP, Piracicaba.

CCEE. CÂMARA DE COMERCIALIZAÇÃO DE ENERGIA ELÉTRICA. **Infomercado**: Dados individuais, 2021. Disponível em: <http://www.ccee.org.br>. Acesso em: 18 de maio de 2021.

CHERNEY, J. H. et al. Potential of brown-midrib, low-lignin mutants for improving forage quality. **Advances in Agronomy**, San Diego, v. 46, p. 157-198, 1991.

CHUPIN, L. et al. Influence of the radial stem composition on the thermal behaviour of miscanthus and sorghum genotypes. **Carbohydrate Polymers**, Barking, v. 167, p. 12-19, 2017.

CONAB. Companhia Nacional de Abastecimento. Nono levantamento da safra brasileira de grãos (safra 2019/2020). Brasília: Conab, v. 7, n. 9, 2020. 31p.

CONAB. Companhia Nacional de Abastecimento. Companhia Nacional de Abastecimento. Oitavo levantamento (Safra 2020/2021). Brasília: Conab, v. 8, n. 8, 2021. 115p.

CORRÊA-FERREIRA, B. S.; SOSA-GÓMEZ, D. R. **Percevejos e o sistema de produção soja-milho**. Documento 397, ISSN 2176-2937, Embrapa soja, Londrina, 2017, 99p.

CORTEZ, M. G. R.; WAQUIL, J. M. Influência de cultivar e nível de infestação de *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) no rendimento do sorgo. **Anais da Sociedade Entomológica do Brasil**, Londrina, v. 26, n. 2, p. 407-410, 1997.

CRUZ, I; ALVARENGA, C. D; FIGUEIREDO, P. E. F. Biologia de *Doru luteipes* (Scudder) e sua capacidade predatória de ovos de *Helicoverpa zea* (Boddie). **Anais da sociedade entomológica do Brasil**, Jaboticabal, v. 24, n. 2, p. 273-278, May. 1995.

CRUZ, I.; BIANCO, R.; REDOAN, A. C. M. Potential risk of losses in maize caused by *Dichelops melacanthus* (DALLAS) (HEMIPTERA: PENTATOMIDAE) in Brazil. **Revista Brasileira de Milho e Sorgo**, Sete Lagoas, v. 3, n. 15, p.386-397, nov. 2016.

DAVIS, F.M.; NG S.S.; WILLIAMS, W. P. Visual rating scales for screening whorl-stage corn for resistance to fall armyworm. Mississippi Agricultural & Forestry Experiment Station. **Technical Bulletin**, v. 186, p. 1-9, 1992.

DEQUECH, S. T. B. et al. Population fluctuation of *Spodoptera frugiperda* eggs and natural parasitism by *Trichogramma* in maize. **Acta Scientiarum Agronomy**, Maringá, v. 35, n. 3, p. 295–300, 2013.

DIEN, B. S. et al. Improved sugar conversion and ethanol yield for forage sorghum (*Sorghum bicolor* L. Moench) lines with reduced lignin contents. **Bioenergy Research**, Bethesda, v. 2, n. 3, p. 153-164, 2009.

DOWD, P. F.; FUNNELL-HARRIS, D. L.; SATTLER, S. E. Field damage of sorghum (*Sorghum bicolor*) with reduced lignin levels by naturally occurring insect pests and pathogens. **Journal of Pest Science**, Innsbruck v. 89, n. 4, p. 885-895, 2016.

DOWD, P. F.; SATTLER, S. E. *Helicoverpa zea* (Lepidoptera: Noctuidae) and *Spodoptera frugiperda* (Lepidoptera: Noctuidae) Responses to *Sorghum bicolor* (Poales: Poaceae) Tissues From Lowered Lignin Lines. **Journal of Insect Science**, v. 15, n. 1, 2015.

DUARTE, M. M.; ÁVILA, C. J.; SANTOS, V. danos e nível de dano econômico do percevejo barriga verde na cultura do milho**. Revista Brasileira de Milho e Sorgo**, v.14, n.3, p. 291-299, 2015.

EBLING, T. L.; KUNG JR, L. A comparison of processed conventional corn silage to unprocessed and processed brown midrib corn silage on intake, digestion, and milk production by dairy cows. **Journal of Dairy Science**, v. 87, n. 8, p.2519-2526, 2004.

ERB, M. Plant defenses against herbivory: closing the fitness gap. **Trends Plant Science.** v. 23, p. 187–194, 2018.

EHRLICH, P. R.; RAVEN, P. H. Butterflies and plants: a study in coevolution. **Evolution**, Malden, v. 18, n. 4, p. 586-608, 1964.

FAO. Sorghum and millets in human nutrition. Rome, 1995. (FAO. Food and Nutrition Series, 27). Disponível em: <http://www.fao.org/docrep/T0818E/ T0818E00.htm>. Acesso em: 18 maio. 2021.

FERNANDES, P. H. R.; et al. Damage by the green-belly stink bug to corn. **Pesquisa Agropecuária Brasileira**, Rio de Janeiro, v.55, e01131, 2020.

GASSEN, D.N. Insetos associados à cultura do trigo no Brasil. Passo Fundo: Embrapa- CNPT (**Circular Técnica, 3**). GASSEN, D.N. Manejo de pragas associadas à cultura do milho. Passo Fundo: Embrapa- Aldeia Norte. 134p, 1996.

GATEHOUSE, J. A. Plant resistance towards insect herbivores: a dynamic interaction. **New Phytologist**, Cambridge, v. 156, p. 145-169, 2002.

GONÇALVES, A. L. et al. Adaptação de *Spodoptera frugiperda* O. E Smith, 1797) (Lepidoptera: Noctuidae) em diferentes genótipos de sorgo sacarino. In: III Simpósio de Entomologia, 01 a 05 de Agosto de 2011, Viçosa, MG.

GRIGOLLI, J. F. J. et al. Estratégias de controle químico do percevejo barriga-verde *Dichelops melacanthus* (Dallas) (heteroptera: Pentatomidae) no sistema de sucessão soja e milho safrinha. In: Congresso nacional de milho e sorgo, 31. Bento Gonçalves. Milho e sorgo: inovações, mercados e segurança alimentar: anais. Sete Lagoas: Associação Brasileira de Milho e Sorgo, 2016.

HSIEH, J.; PI, C. P. Genetic study on aphid resistance in sorghum. **Agricultural Association of China**, v. 117, p. 6–14, 1982.

HOFFMANN-CAMPO, C. B.; GRAÇA, J. P. **O papel dos metabólitos secundários na resistência de plantas a insetos**. In: BALDIN, E. L. L.; VENDRAMIM, J. D. LOURENÇÃO, A. L. (eds). Resistência de plantas a insetos- Fundamentos e Aplicações. Piracicaba, São Paulo, Brasil: Fealq, 2019. p. 99-126.

IBGE- Instituto Brasileiro de Geografia e Estatística, 2020. https://www.ibge.gov.br/) Disponível em: https://agenciadenoticias.ibge.gov.br/agencia-sala-de-imprensa/2013-agencia-de-noticias/releases/27911-em-maio-ibge-preve-alta-de-1-8-na-safra-de-graos-de-2020. Acesso em: 09 jun. 2020.

JORGENSON, L. R. Brown midrib in maize and its linkage relations. **Journal of the American Society of Agronomy**, Washington, n. 23, p. 549-557, 1931.

KOCH, K. G et al. **Tolerância**. In: BALDIN, E. L. L.; VENDRAMIM, J. D. LOURENÇÃO, A. L. (eds). Resistência de plantas a insetos- Fundamentos e Aplicações. Piracicaba, São Paulo, Brasil: Fealq, 2019. p. 225-246.

KOGAN, M.; ORTMAN, E. E. Antixenosis- a new term proposed to replace Painter´s “nonpreference” modality of resistance. **Bulletin of Entomological Society of America**, v. 24, p. 175-176, 1978.

KNOLHOFF, L. M.; HECKEL, D. G. Behavioral assays for studies of host plant choice and adaptation in herbivorous insects. **Annual Review of Entomology**, Stanford, v. 59, p. 263-278, 2013.

KRIMMEL, B.; PEARSE, I. S. Tolerance and phenological avoidance of herbivory in tarweed species. **Ecology**, v. 97, p. 1357–1363, 2016.

LARA, F.M. et al. Comportamento de genótipos de sorgo em relação ao ataque de *Diatraea saccharalis* (Fabr., 1794). **Anais da Sociedade Entomológica do Brasil**, Londrina, v. 8, p. 125-130, 1979.

LARA, F. M. **Princípios de Resistência de plantas a insetos**. São Paulo: Ícone Editora, 1991. 336 p.

LARA, F. M. et al. Resistência de genótipos de sorgo a *Contarinia sorghicola* (Coq.) (Diptera: Cecidomyiidae) e *Diatraea saccharalis* (Fabr.) (Lepidoptera: Pyralidae) e influência sobre parasitoides. **Anais da Sociedade Entomológica do Brasil**, Londrina, v. 26, n. 2, p. 327-333, 1997.

LÓPEZ, J.; PITRE, H. N.; MECKENSTOCK, D. H. Influence of nitrogen fertilizer on resistance to fa1 1armyworm (Lepidoptera: Noctuidae) in tropical Honduran landrace sorghum. **Ceiba**, Tegucigalpa, v. 41, n. 1, p. 35-39, 2000.

LUCENA, A. I. T. Comportamento de genótipos de sorgo granífero em relação a *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera, Noctuidae) e tipos de resistência envolvidos. Departamento de Entomologia, ESALQ/USP. Piracicaba, SP. (Dissertação MS) 105 p., 1978.

MARTINO, H. S. D. et al. **Por que utilizar o sorgo na alimentação humana?** In: KARAM, D.; MAGALHÃES, P. C. (Ed.). Eficiência nas cadeias produtivas e o abastecimento global. Sete Lagoas: Associação Brasileira de Milho e Sorgo, 2014. cap. 11, p. 95-114, 2014.

MAY, A. **Cultivo do Sorgo biomassa para a cogeração de energia elétrica**. In: MAY, A.; SILVA, D. D.; SANTOS, F. C. Embrapa Milho e Sorgo, Sete Lagoas-MG, p. 69, Documentos 152, 2013.

MCMILLIAN, W. W.; STARKS, K. J. Greenhouse and laboratory screening of sorghum lines for resistance to fall armyworm larvae. **Journal of Economic Entomology**, Lanham, v. 60, p. 1462-1463, 1967.

MENDES, S. M. et al. Manejo de pragas na cultura do sorgo. **Informe Agropecuário**, Belo Horizonte, v. 35, n. 278, p. 89-99, 2014.

MENEZES, C.B. et al. Capacidade combinatória de linhagens de sorgo granífero cultivados em segunda safra. **Boletim de Pesquisa e Desenvolvimento 127**, Embrapa Milho e Sorgo, Sete Lagoas, 2015.

MICHAUD, J. P.; SLODERBECK, P. E. Russian wheat aphid: an introduced pest os small grains in the high plains. Kansas State University Agricutural Experiment Satation an Cooperative Extension Service, 2005. 4p. Disponível em: http://www.bookstore.ksre.ksu.edu/pubs/MF2666.pdf. Acesso em: 18 de maio. 2021.

OBA, M.; ALLEN, M. S. Effects of brown midrib 3 mutation in corn silage on dry matter intake and productivity of high yielding dairy cows. **Journal of Dairy Science**, v.82, p.135-142, 1999.

PAINTER, R. H. **Insect resistance in crop plants**. New York, USA: McMillan, 1951.

PARRELLA, R. A. C. **Cultivo do sorgo biomassa para a cogeração de energia elétrica**. In: MAY, A.; SILVA, D. D.; SANTOS, F. C. Embrapa Milho e Sorgo, Sete Lagoas-MG, p. 69, Documentos 152, 2013

PAUDYAL, S. et al. Categories of resistance to sugarcane aphid (Hemiptera: Aphididae) among sorghum genotypes. **Journal of Economic Entomology**, Lanham, v. 112, n. 4, p. 1932–1940, 2019.

PETERSON, R. K. D.; HIGLEY, L. G. Illuminating the black box: the relationship between injury and yield. In: Peterson, R. K. D., Higley, L. G., eds**. Biotic Stress and Yield Loss**. New York: CRC Press, p. 1–12, 2001.

PETERSON, R. K. D.; VARELLA, A. C.; HIGLEY, L. G. Tolerance: the forgotten child of plant resistance. **Peer J**, v. 5: e3934, 2017.

NAGOSHI, R. N.; MEAGHER, R. L. Review of fall armyworm (Lepidoptera: Noctuidae) genetic complexity and migration. **Florida Entomologist**, Gainesville, v. 91, n. 4, p. 546-554, 2008.

ROSSETTO, C. J. Resistência de plantas a insetos. Piracicaba: Esalq-Usp, 1973, 171p.

ROSSETTO, C. J.; BANZATTO, N. V.; IGUE, T. Comportamento de variedades de sorgo em relação a *Contarinia sorghicola* e *Rhopalosiphum maidis* em diferentes épocas de plantio. **Bragantia**, v. 35, p. 365-374, 1976.

ROZA-GOMÉS, M. F. et al. Injúrias de quatro espécies de percevejos pentatomídeos em plântulas de milho. **Ciência Rural**, v. 41, n. 7, p. 1-5, 2011.

RUBIN, E. M. Genomics of cellulosic biofuels. **Nature**, New York, v. 454, p.841-845, 2008.

SANTOS, F. G.; CASELA, C. R.; WAQUIL, J. M. Melhoramento do sorgo. In: BORÉM, A. (ed.). **Melhoramento de espécies cultivadas**. Viçosa, Minas Gerais, Brasil: UFV, p. 605-658, 2005.

SANTOS, L. M. et al. Fertilidade e longevidade de *Spodoptera frugiperda* (J.E.Smith) (Lepidoptera: Noctuidae) em genótipos de milho. **Ciência Rural**, Santa Maria, v. 34, n. 2, p. 345-350, 2004.

SANTOS, L. A. O.; MIHSFELDT, L. H. Capacidade de busca e de parasitismo de *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) em lagartas de *Diatraea saccharalis* (Fabricius) (Lepidoptera: Crambidae). **EntomoBrasilis**, Vassouras, v. 7, n. 2, p. 106-109, 2014.

SANTOS, R. C. S. et al. Correlações entre os parâmetros de qualidade da madeira e do carvão vegetal de clones de eucalipto. **Scientia Agricola**, Piracicaba, v. 39, n. 90, p. 221-230, 2011.

SANTOS, T. M.; WAQUIL, J. M.; ANDRADE, R. V. Avaliação do germoplasma de sorgo para resistência à *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera: Noctuidae). Embrapa Milho e Sorgo, Sete Lagoas, MG. p. 98-100, 1992.

SCHOLZ, S. S. et al. Insect herbivory-elicited GABA accumulation in plants is a wound-induced, direct, systemic, and jasmonate-independent defense response. Frontiers in plant science, v. 6, p. 1-11, 2015.

SCHOONHOVEN, L. M.; VAN LOON, J. J. A.; DICKE, M. Insect-plant biology. 2. ed. Oxford: Oxford University Press, 2005. 421 p.

SILVA, D. D. et al. Principais doenças do sorgo. **Informe Agropecuário**, Belo Horizonte, v. 35, n. 278, p. 102-111, 2014.

SILVA, F. A. C.; PANIZZI, A. R. **Interações inseto-planta**. In: BALDIN, E. L. L.; VENDRAMIM, J. D. LOURENÇÃO, A. L. (eds). Resistência de plantas a insetos-Fundamentos e Aplicações. Piracicaba, São Paulo, Brasil: Fealq, 2019. p. 65-89.

SILVA, T. I. et al. Produtividade de variedades de sorgo em diferentes arranjos populacionais em primeiro corte e rebrota. **Revista Espacios**, Buenos Aires, v. 38, n. 27, p. 16-27, 2017.

SPEROTTO, R. A. et al. Crops responses to mite infestation: It's time to look at plant tolerance to meet the farmers' needs. **Frontiers in Plant Science**, v. 9, n. 556, 5p., 2018.

STOUT, M. J. Reevaluating the conceptual framework for applied research on hostplant resistance. **Insect Science**, v. 20, p. 263-272, 2013.

STOWE, K. A. et al. The evolutionary ecology of tolerance to consumer damage. **Annual Review of Ecology, Evolution, and Systematics**, v. 31, p. 565–595, 2000.

TRUMBLE, J. T., KOLODNY-HIRSCH, D. M.; TING, I. P. Plant compensation for arthropod herbivory. **Annual Review of Entomology**. 38, 93–119, 1993.

USDA- United States Department of Agriculture Foreign Agricultural Service. Grain: World Markets and Trade. https://public.govdelivery.com/accounts/USDAFAS/subscriber/new- Acesso em 18 de maio de 2021, May, 2021, 59p.

VENDRAMIM, J. D.; GUZZO, E. C. **Resistência de plantas e a bioecologia e nutrição dos insetos**. In: PANIZZI, A. R.; PARRA, J. R. P. (Eds.). Bioecologia e nutrição de insetos: base para o manejo integrado de pragas. Embrapa Informação Tecnológica, Brasília, 2009. p. 1055-1105.

VENDRAMIM, J. D.; GUZZO, E. C.; RIBEIRO, L. P. **Antibiose**. In: BALDIN, E. L. L.; VENDRAMIM, J. D. LOURENÇÃO, A. L. (eds). Resistência de plantas a insetos-Fundamentos e Aplicações. Piracicaba, São Paulo, Brasil: Fealq, 2019. p. 185-214.

VILELA, M.; SANTOS. et al. Influence of *Diatraea saccharalis* (Lepidoptera: Crambidae) infestation on sweet sorghum productivity and juice quality. **African Journal of Agricultural Research**, v. 12, n. 39, p. 2877-2885, 2017.

WHITTAKER, R. H.; FEENY, P. P. Allelochemics: chemical interactions between species. **Science**, v. 171, n. 3973, p. 757-770, 1971.

WAQUIL, J. M. et al. Comportamento de cultivares de sorgo sacarino em relação à broca-da-cana-de-açúcar, *Diatraea saccharalis* (F. 1794) em condições de campo. In: Anais VI CBE/SEB/Campinas, SP. 3 a 9/02/80, R. 108, 1980.

WAQUIL, J. M. et al. Resistance of commercial hybrids and lines of sorghum, *Sorghum bicolor* (L.) Moench., to *Diatraea saccharalis* (Fabr.) (Lepidoptera: Pyralidae). **Neotropical Entomology**, Londrina, v. 30, n. 4, p. 661-668, 2001.

WAQUIL, J. M.; SANTOS, T. M. Avaliação de cultivares de sorgo em relação à lagarta-do-cartucho, *Spodoptera frugiperda*. In: Anais do 18º Congresso Nacional de Milho e Sorgo. Realizado de 29/julho a 03/agosto de 1990, Vitória, ES. p. 88., 1990.

WAQUIL, J. M.; VIANA, P. A.; CRUZ, I. **Manejo de pragas na cultura do sorg**o. Embrapa Milho e Sorgo, Sete Lagoas, v. 27, 25p. 2003. Circular Técnica.

WAQUIL, J.; OLIVEIRA, L. J. Percevejo barriga-verde: nova prioridade das culturas em sucessão à soja. **Embrapa Milho e Sorgo-Artigo de divulgação na mídia** (INFOTECA-E), 2009.

XIN, Z. et al. Applying genotyping (TILLING) and phenotyping analyses to elucidate gene function in a chemically induced sorghum mutant population. **BMC Plant Biology**, Stuttgart, v. 8, n. 103, p. 1-14, 2008.

ZARATE, S. I.; KEMPENA, L. A.; WALLING, L. L. Silverleaf Whitefly Induces Salicylic Acid Defenses and Suppresses Effectual Jasmonic Acid Defenses. Plant Physiology, v. 142, p. 866-875, 2007.

SEGUNDA PARTE – ARTIGOS

ARTICLE 1- Resistance of *bmr* energy sorghum hybrids to sugarcane borer and fall armyworm

Souza, CSF[1]., Souza, BHS[1]., Parrella, RAC[2]., Simeone, MLF[2]., Nascimento, PT[1]., França, JCO[1]., Lima, PF[3]., & Mendes, SM[2]*

[1] Departament of Entomology, Universidade Federal de Lavras, Campus Universitário, P. O. Box 3037, Lavras, MG, 37200-000, Brazil.

[2]Embrapa Milho e Sorgo, Rodovia MG 424, Km 45, P. O. Box 285, Sete Lagoas, MG, 35701-970, Brazil.

[3]Campus de Sete Lagoas, Universidade Federal de São João Del Rei, Rodovia MG-424, Km 47, Indústrias, P.O. Box 56, Sete Lagoas, MG, 35701-970, Brazil.

*Corresponding author: Simone Martins Mendes**,** E-mail: simone.mendes@embrapa.br

Artigo aceito pela revista Brazilian Journal Biology 1,266 A2

(With 3 figures and 3 tables).

Short running title: Resistance of *bmr* energy sorghum for sorghum pests

Orcid number:

Souza CSF: https://orcid.org/0000-0002-2740-9223

Souza BHS: https://orcid.org/0000-0002-2802-2688

Parrella RAC : https://orcid.org/0000-0001-6599-7487

Simeone MLF: https://orcid.org/0000-0002-2003-0341

Nascimento PT: https://orcid.org/0000-0003-4366-4918

França, JCO: https://orcid.org/0000-0002-8515-2120

Lima, PF: https://orcid.org/0000-0002-5163-4236

Mendes SM: https://orcid.org/0000-0002-9773-9017

Abstract

The lower lignin content in plants species with energy potential results in easier cellulose breakdown, making glucose available for ethanol generation. However, higher lignin levels can increase resistance to insect attack. The objective of this work was to evaluate the susceptibility of a *bmr*-6 biomass sorghum (a mutant genotype with a lower concentration of lignin) to important pests of sorghum energy, *Diatraea saccharalis* and *Spodoptera frugiperda*. Experiments were performed in the laboratory and greenhouse to evaluate the development of these pests on the biomass sorghum *bmr* hybrids BR007, BR008, and TX635 and their respective conventional near-isogenic genotypes (without the *bmr* gene). The lignin content was higher in non-*bmr* hybrids, but in the parameters evaluated in insects, there was variation between treatments, but not in relation to being bmr or not. The lowest survival of *S. frugiperda* was observed in the BR008 hybrid, both *bmr* and non-*bmr*. The *S. frugiperda* injury scores on plants in the greenhouse were high (>7) in all treatments. For *D. saccharalis*, there was no difference in larval survival in the laboratory, but in the greenhouse, the BR007 hybrid, both *bmr* and non-b*mr*, provided greater survival. Due the need to diversify the energy matrix and the fact that greater susceptibility of the *bmr* hybrids to either pests was not found in this study, these results hold promise for cultivation of these biomass sorghum hybrids for the production of biofuels.

Keywords: plant resistance, energy sorghum, *Diatraea saccharalis*, *Spodoptera frugiperda*

Resistência de híbridos de sorgo energia *bmr* à broca da cana-de-açúcar e à lagarta do cartucho

Resumo

O menor teor de lignina em espécies de plantas com potencial energético resulta na maior facilidade de quebra da celulose, disponibilizando glicose para geração de etanol. Porém, maiores teores de lignina representam um fator de resistência ao ataque de insetos-praga. O objetivo deste trabalho foi avaliar a suscetibilidade de um sorgo biomassa *bmr*-6 (um genótipo mutante com menor concentração de lignina) à importantes pragas do sorgo energia, *Diatraea saccharalis* e *Spodoptera frugiperda*. Foram realizados experimentos em laboratório e casa de vegetação, avaliando o desenvolvimento destas pragas nos híbridos de sorgo biomassa *bmr* 007, 008, TX635 e seus respectivos genótipos isogênicos convencionais (sem o gene *bmr*). O teor de lignina foi maior nos híbridos não *bmr*, mas nos parâmetros avaliados nos insetos, houve variação entre os tratamentos, mas não em relação a ser ou não *bmr*. A menor sobrevivência de *S. frugiperda* foi verificada no híbrido BR008 tanto *bmr* quanto não *bmr*. As notas de injúria por *S. frugiperda* no sorgo em casa de vegetação foram altas (>7) em todos os tratamentos. Para *D. saccharalis*, não houve diferença significativa para a sobrevivência larval em laboratório, mas em casa de vegetação o híbrido BR007 tanto *bmr* quanto não *bmr* proporcionaram maior sobrevivência. Diante da necessidade de diversificar a matriz energética e o fato de que não foi comprovada neste estudo maior suscetibilidade dos híbridos *bmr* a ambas as pragas, estes resultados são promissores para o cultivo desses híbridos de sorgo biomassa para produção de biocombustíveis.

Palavras-chave: Resistência de plantas, sorgo energia, *Diatraea saccharalis*, *Spodoptera frugiperda*.

Introduction

One of the impediments to the conversion of biomass into biofuels is the presence of the polymer lignin, which interferes with the release of sugars from the cell wall polysaccharides cellulose and hemicellulose during enzymatic saccharification (Rubin, 2008; Dien et al., 2009). Despite the increase in use of starch- and sugarcane-based biofuels, the fuels produced from lignocellulosic biomass are greenhouse-gas-favorable alternative energy sources (Rubin, 2008). Lignocellulosic biomass constitutes the residues of plants, such as elephant grass, coconut husk, and biomass sorghum, which do not have the sugar contents found in sugarcane and sweet sorghum (Santos et al., 2011; Hernández et al., 2015).

In Brazil, there has been a significant increase in export of electricity from biomass in last five years. The share of biomass sources out of the total composition of exported energy in the National Interconnected System (National Interconnected System) increased from 17% in 2013 to 19% in 2018 (EPE, 2019). This increase in the demand for heat generation from biomass is due to its lower cost and higher practicality, since it is used directly through combustion in ovens and boilers. Another important factor is that burning of fossil fuels emits various contaminants that cause local, regional, and global environmental impacts. In the Nationally Determined Contribution (NDC), Brazil is committed to reducing greenhouse gas emissions by 43% by 2030 and increasing the share of sustainable bioenergy in the energy matrix to approximately 18% by expanding its biofuels consumption, by increasing the share of advanced biofuels, known as second-generation biofuels (EPE, 2019).

Biomass sorghum (*Sorghum bicolor* L. Moench) is a promising lignocellulosic raw material because it is a productive crop adapted to water stress conditions, which is an advantage in a scenario that demands water savings, in addition to having a well-understood production system and being adapted to different environmental conditions (Silva et al., 2017). The biomass sorghum under suitable photoperiod conditions, has the potential to produce up to

102.22 t ha^{-1} of fresh biomass yield, its cultivation is completely mechanized, and the plants have calorific power similar to that of sugarcane, eucalyptus and elephant grass needed for burning, between 16 e 19 $MJ \cdot kg^{-1}$ (May, 2013; Parrella, 2013). Sorghum biomass can be used as a raw material for bioenergy through the production of second-generation ethanol as a liquid biofuel, and in energy generation by direct biomass burning, as well as food for ruminants (Cherney et al., 1991 Zegada-Lizarazu and Monti, 2012; Reddy and Blummel, 2020). The *brown midrib* (*bmr*) mutant of biomass sorghum is an alternative in energy sector for use in processes in which lignin is an obstacle, such as the production of second-generation ethanol. The simplification of saccharification process is very important because the cost of cellulases to degrade biomass is a limiting factor for the economic production of biofuels. For this, the raw material needs to have a low lignin content, as the biomassa sorghum *bmr*, because cellulose is a glucose polymer that has to be broken down, so a lower lignin content means easier cellulose breakage, making glucose available for ethanol generation (DIEN, et al., 2009). With high productivity and contribute to the strategy of a green economy with the supply of raw material in the distilleries, it is considered that sorghum biomass is a renewable and low-cost source of energy, being economically viable (Parrella, 2013; Vendruscolo et al., 2016). In addition, this mutant genotype may provide better digestibility to cattle because lignin is the nondigestible fraction of the plant that supports the stem. The higher the lignin content, the lower the silage quality and digestibility, as it is the factor that most limits the availability of cell wall components for bovine rumen microorganisms (Reddy and Blummel, 2020). The lignin, cross-links cellullose and can be considered as “cell glue” that gives resistance to plant tissue and gives rigidity to the cell wall, thus factors such as the incidence of pests can make the plant even more fragile (Rubin, 2008).

The occurrence of pest insects is a problem for sorghum crops, and the sugarcane borer *Diatraea saccharalis* (Fabricius, 1794) (Lepidoptera: Crambidae) is one of the major pests. The greatest injury sugarcane borers can cause to a plant that can reach five meters in height is to make the stem fragile and susceptible to lodging, in addition to hindering the flow of sap and photoassimilates in the plant (Mendes et al., 2014; Silva et al., 2017). The fall armyworm, *Spodoptera frugiperda* (Smith, 1797) (Lepidoptera: Noctuidae), is also one of the main sorghum pests, causing defoliation and thereby reducing leaf area for photosynthesis. The presence of higher lignin content in plants can be a resistance trait to insect pests, especially lepidopterans (Dow et al., 2016). Thus, the absence of this characteristic could reduce the natural morphological barrier of plants and increase their susceptibility to pest infestation. This possibility has not been fully elucidated in sorghum and results vary widely between studies (Dowd et al., 2015, 2016).

This study evaluated the susceptibility of bmr-6 sorghum to *D. saccharalis* and *S. frugiperda*, if the lower lignin content in the mutant plants favors feeding and pest performance. Knowledge of this information is highly important, since reducing the lignin content in the bioenergy feedstock could cause greater susceptibility to pest attack because this phenolic compound overall represents a plant defense trait against herbivorous insects (Dowd et al. 2016; Vendramim and Guzzo, 2009). Plants have chemical mechanisms for defense against insects, such as nitrogen compounds, terpenoids and phenolics. These compounds can be toxic to insects, preventing or altering their normal development (Vendramim et al., 2019). Lignin is made up of three main phenolic components: p-coumaryl alcohol (H), coniferyl alcohol (G) and synapyl alcohol (S), are aromatic polymers that vary in their branches and condense into different structures (Rubin, 2008). Therefore, the objective of this work was to evaluate the susceptibility of a *bmr*-6 biomass sorghum (a mutant genotype with a lower concentration of lignin) to important pests of sorghum energy, *Diatraea saccharalis* and *Spodoptera frugiperda*.

Material and Methods

Experimental site and conditions

Experiments with both pest species were carried out in a greenhouse and at the Laboratory of Ecotoxicology and Insect Management of Embrapa Milho e Sorgo located in Sete Lagoas, Minas Gerais state, Brazil, in a climate-controlled room with 25 ± 2 °C temperature, 12-hour photoperiod, and 60 ± 10% relative humidity.

Effect of the presence of the *bmr* gene on the development of sugarcane borer

The biomass sorghum *bmr* hybrids BR007, BR008, and TX635 and their near-isogenic genotypes (without the *bmr* gene) were evaluated in a laboratory bioassay with six genotypes (=treatments). To obtain the leaves for feeding the insects, the hybrids were grown in the field, the soil in the region is of the red yellow latosol, with medium and silty texture (Embrapa, 2013). The design of the experiment was in randomized blocks, with four replications, each experimental plot consisting of three lines of 5 m in length and 0.7 m in spacing. The soil was fertilized with 400 kg ha^{-1} of NPK 8-28-16, and at 15 days after emergence, cover fertilization was performed using 200 kg ha^{-1} of urea. The plants were thinned 15 days after emergence, leaving eight plants per meter, in a total of 40 plants per row in plots. Management practices performed according to May (2013), except that no insecticides were sprayed in the experimental area.

Testing insects were obtained from a rearing colony in the laboratory. Briefly, larvae were individually reared on artificial diet based on cooked beans, wheat germ, and casein (Bowling, 1967). Adults were transferred to cylindrical mating cages (40 cm h x 30 cm in diam.)

containing moth food (10% sugar and 5% ascorbic acid in water) and white sulfite paper on the inner walls for oviposition. Collected egg masses were let to hatch, and neonates transferred to the artificial diet (Cruz, 2000). Newly hatched larvae obtained from the laboratory rearing colony were individually placed in 50-mL plastic cups sealed with acrylic lids, according to the method adapted from Mendes et al. (2011) for *S. frugiperda*.

Whorl leaves from the *bmr* and non-*bmr* sorghum were collected from the plants when there were between six and eight fully developed leaves (stages V6-V8) (Magalhães and Durães, 2003) and taken to the laboratory, where they were cleaned and cut into pieces of approximately 50 cm^2. The leaves in the bioassay containers were replaced every 48 hours.

The survival and biomass of *D. saccharalis* larvae were evaluated 10 days after the beginning of the experiment. The evaluation was performed for 10 days, which is the duration of the behavior of *D. saccharalis* in seeking the plant stem; after that, the larvae no longer feed on the leaves. Data on these biological parameters were subjected to the Shapiro-Wilk and Bartlett tests to check the assumptions of normality of residuals and homoscedasticity, respectively. They were then subjected to analysis of variance (ANOVA), and means of treatments were compared by Tukey's test ($\alpha=0.05$).

A second experiment was conducted in a greenhouse with the three biomass sorghum *bmr* hybrids (BR007, BR008, TX635) and their near-isogenic genotypes (without the *bmr* gene). The hybrids were planted in a completely randomized design to evaluate the resistance (antixenosis/antibiosis) to sugarcane borer. Planting was performed in 20-L pots filled with soil fertilized with 50 g of 08-28-16 NPK and 0.3% Zn/100 kg·v. For each treatment, 20 pots with three plants were used, and each pot was considered a replicate. At the four-to-six-developed leaf stage (Magalhães and Durães, 2003), the plants were infested with five newly hatched *D. saccharalis* larvae per plant, totaling 15 larvae per pot. Injury caused by bored larvae was evaluated every 60 days after infestation.

For injury evaluation, plants were cut close to the ground and opened longitudinally to detect the presence of galleries bored in the stem of plants. The parameters evaluated were plant height (cm), bored internodes (%), gallery size (cm), number of galleries per plant, survival (%) and biomass (mg) of larvae and pupae recovered from the plants. Data recorded for these parameters were subjected to the Shapiro-Wilk and Bartlett tests to check the assumptions of normality of residuals and homoscedasticity, respectively, and then analyzed by ANOVA. The means of treatments were compared by Tukey's test (α=0.05). The analyses were performed using the statistical R software version 3.5.3 (R Development Core Team 2019).

Effect of the presence of the *bmr* gene on the development of fall armyworm

This experiment was carried out in the same manner as described for the sugarcane borer. The variables evaluated in *S. frugiperda* were larva-to-adult survival (%), biomass (mg) of larvae at 10 days, and biomass (mg) of pupae at 48 hours. To evaluate survival, a group of 10 individuals was considered one replicate, and there were nine replicates (90 individuals) in the experiment. For the other biological variables, one individual was considered a replicate. Because mortality was different in each treatment, the number of individuals (replicates) available for statistical analysis varied.

The adaptation index (AI) proposed by Boregas et al. (2013) was used to evaluate the larval performance of *S. frugiperda* whereby: AI= larval survival (%) × pupal biomass (mg)/larval development period (days); in the calculation of AI, pupal biomass was used to estimate the fecundity of adults (Barah and Sengupta, 1991). Correlation coefficients were also estimated to correlate the biological variables with the AI of *S. frugiperda*.

For the survival analysis, a curve was generated in SigmaPlot software 10.0® (Systat Software Inc.) from the output of the chi-squared test. For the larval and pupal biomass data, the Shapiro-Wilk test was performed to check normality and the Bartlett test was used to check for homogeneity of variances. As data did not follow a normal distribution or exhibited heterogeneity of variances, was performed using generalized linear model (GLM) and negative binomial distribution, and the means of treatments were compared by Tukey's test (α=0.05). The analyses were performed using the statistical R software version 3.5.3 (R Development Core Team 2019).

The experiment to evaluate plant injury in the greenhouse followed the same procedure described for the sugarcane borer. Seven replicates were used per treatment, totaling 42 potted plants. Plants at the four-to-six-developed leaf stage were infested with five newly hatched *S. frugiperda* larvae per plant, totaling 15 larvae per pot. The pots were covered with a voile fabric cage (1.20 cm × 55 cm) to prevent the larvae from escaping.

Evaluation of plant injury was made through visual injury scores according to the scale proposed by Davis and Williams (1992) for corn and adapted to sorghum. Evaluations were performed at 7, 14, and 21 days after larval infestation. The scores assigned to the plants ranged from 0 to 9, as follows: 0 = no injury; 1 = presence of pinholes (more than one pinhole per plant); 2 = pinholes and one to three small circular lesions (up to 1.5 cm); 3 = one to five small circular lesions (up to 1.5 cm), plus one to three elongated lesions (up to 1.5 cm); 4 = one to five small circular lesions (up to 1.5 cm), plus one to three elongated lesions (> 1.5 cm and < 3.0 cm); 5 = one to three large elongated lesions (>3 cm) in one to two leaves, plus one to five holes or elongated lesions (up to 1.5 cm); 6 = one to three large elongated lesions (>3 cm) in two or more leaves, plus one to three large holes (>1.5 cm) in two or more leaves; 7 = three to five large elongated lesions (> 3.5 cm) in two or more leaves, plus one to three large holes (greater than 1.5 cm) in two or more leaves; 8 = many elongated lesions (> 5 cm) of all sizes in most leaves, many medium to large holes (> five) larger than 3 cm in many leaves; 9 = almost completely destroyed leaves. The injury scores were analyzed by calculating their confidence intervals at 95% probability.

Bromatological analyses

Bromatological analyses were performed in the sorghum hybrids to identify possible differences in chemical composition between *bmr* and non-*bmr* genotypes. To determine the dry matter mass, the plants were placed in paper bags and dried in an oven at 65 °C for 72 hours. The samples were milled in a knife mill with a 2-mm sieve (Wiley mill, Arthur H. Thomas, Philadelphia, PA, USA) and prepared for chemical analysis.

The contents of acid detergent fiber (ADF), neutral detergent fiber (NDF), and acid detergent lignin (ADL) were determined according to the method proposed by Robertson and Van Soest (1981). The cellulose content was calculated as the difference between the ADF and lignin contents, and the hemicellulose content was calculated as the difference between NDF and ADF by near-infrared (NIR) spectroscopy (NIRFlex 500, Buchi Brasil Ltda, Valinhos, SP, Brazil). The calibration equations for the analysis of ADF, NDF, lignin, and calorific value were based on values obtained and stored in the Embrapa Corn and Sorghum database, which covers a total of 400 samples.

Data obtained from the chemical analyses were subjected to the Shapiro-Wilk and Bartlett tests to check the assumptions of normality of residuals and homoscedasticity, respectively, and were analyzed by ANOVA. The means of treatments were compared by Tukey's test ($\alpha=0.05$). The analyses were performed using the statistical R software version 3.5.3 (R Development Core Team 2019).

Results

Effect of the presence of the *bmr* gene on the development of sugarcane borer

There was no difference in larval survival of *D. saccharalis* among the energy sorghum hybrids. Sugarcane borer larvae fed the *bmr* hybrids showed mean 10-day-old biomass 22% higher than larvae reared in the non-*bmr* near-isogenic genotypes (Table 1).

The plant height, total number of internodes, number of healthy and bored internodes, and length and diameter of galleries, had no significant differences. The BR007 hybrid, both *bmr* and non-*bmr*, provided higher percentage survival of *D. saccharalis* than the other hybrids. The TX635 and BR007 hybrids had the highest and lowest mean pupal biomass, respectively (Table 2).

Effect of the presence of the *bmr* gene on the development of fall armyworm

There was difference in larval survival of *S. frugiperda* among the sorghum hybrids. TX635 had the highest percentage survival, followed by BR007 *bmr*, BR007, and TX635 *bmr*. The lowest larval survival was observed in the BR008 hybrid, both in the *bmr* genotype and conventional near-isogenic genotype (Fig 1).

Larval biomass differed between hybrids, with higher biomass in BR007 *bmr*, followed by TX635; the lowest biomass of fall armyworm was obsered in BR008, both *bmr* and non-*bmr*. The biomass of *S. frugiperda* pupae was greater in the BR008 hybrid than in the other sorghum hybrids (Fig 2).

The AI of *S. frugiperda* was 11.64 in the TX635 hybrid, 10.08 in TX635 *bmr*, 11.36 in BR007, 10.45 in BR007 *bmr*, 10.01 in BR008, and 9.07 in BR008 *bmr*, without difference between means. The estimated correlation coefficient between the AI and larval survival was 0.875; between AI and pupal biomass, -0.390; and between AI and larval biomass, -0.877.

The injury scores of *S. frugiperda* in sorghum plants differed among sorghum hybrids. The TX635 hybrid, both *bmr* and non-*bmr*, had a lower injury score at 7 days than at 14 or 21 days after infestation, as did the BR007 *bmr* hybrid. The other hybrids did not differ across the evaluated days. The highest injury scores were found in the TX635 *bmr* and non-*bmr* hybrids, with the highest score (9) observed in the last evaluation date (Fig 3).

Bromatological analyses

The levels (%) of ADF, NDF, and hemicellulose had no differences among the energy sorghum hybrids. The dry matter was highest in the BR007 non-*bmr* hybrid and lowest in the TX635 non-*bmr* hybrid. Lignin percentage was higher in the non-*bmr* hybrids than in the conventional near-isogenic genotypes. Finally, the calorific value (MJ/kg) was highest in the BR008 non-*bmr* hybrid and lowest in TX635 *bmr* (Table 3).

Discussion

The hypothesis of greater susceptibility to attack of sugarcane borer and fall armyworm due to the lower lignin content in *bmr*-6 sorghum hybrids was not supported by our findings. Although microorganisms that can degrade cellulose, hemicellulose, and lignin have been identified in the midgut of *D. saccharalis* larvae, they have a greater capacity to digest cellulose than hemicellulose, and few produce enzymes to degrade lignin (Dantur, 2015). Thus, plant genotypes with lower lignin levels, in theory, could be more consumed by insect pests because lignin is difficult to digest. Our results showed that *D. saccharalis* larval biomass was higher in *bmr* than in non-*bmr* sorghum hybrids. This finding demonstrates the effect of plant biomass on insect development, as the greater the biomass, the greater the insect growth rate is, indicating that the host plant is suitable for herbivore development and does not show resistance (Souza et al., 2019). It is possible that the *bmr* hybrids are more suitable for the development of *D. saccharalis*, which harbors microorganisms capable of digesting lignin, though our survival data do not show such a trend.

The height, total number of internodes, number of healthy and bored internodes, and length and diameter of galleries made by *D. saccharalis* did not show significant differences between *bmr* and non-*bmr* genotypes or among sorghum hybrids. The BR007 hybrid, both *bmr* and non-*bmr*, caused higher *D. saccharalis* percentage survival than the other hybrids; TX635 provided greater pupal biomass; and the non-*bmr* BR007 hybrid, lower pupal biomass. Thus, there was no consistency in the results that would show an effect of the *bmr* gene on *D. saccharalis*. Again, the results of the greenhouse experiment did not indicate higher levels of resistance in the energy sorghum *bmr* genotypes relative to the non-*bmr* genotypes.

Higher survival of *S. frugiperda* larvae was found in the TX635 hybrid than in the respective near-isogenic *bmr* genotype under laboratory conditions. This hybrid had a greater difference in lignin content between the *bmr* and non-*bmr* genotypes, and there may also be other causes of resistance involved besides this trait, which are still unknown. The leaves of the *bmr* genotypes had lower lignin contents, as shown by the results of the bromatological analysis, which was expected. Lower lignin contents may make plants more susceptible to herbivory, since lignin is an important chemical and morphological component of plant resistance that can hinder larval feeding (Dowd et al., 2016). However, the BR008 hybrid, both *bmr* and non-*bmr*, caused lower larval survival and biomass of *S. frugiperda*, which did not differ. Thus, the presence or absence of the *bmr* gene did not alter the larval performance. These results indicate that *S. frugiperda* larvae reached the adult stage in a similar manner in all energy sorghum hybrids. The same occurred for the pupal biomass, as there was no difference of whether the hybrids were *bmr* or not, and the BR008 hybrid provided greater pupal biomass.

Pencoe and Martin (1982) found a significant positive correlation between pupal biomass and adult fertility in *S. frugiperda*. Data obtained in the present study suggest equality in the biology of *S. frugiperda* when fed a *bmr* vs. a non-*bmr* sorghum genotype. Therefore, apparently reducing the lignin content and changing the biomass composition of plants for bioenergy production does not necessarily increase the susceptibility of sorghum to *S. frugiperda* attack, and this process would contribute to the sustainable production of biofuels.

The *S. frugiperda* biological variables were more affected by the effect of hybrid than the *bmr* mutation; the *bmr* genotypes did not negatively affect the insect development. The BR008 hybrid was the one that most negatively affected the biology of *S. frugiperda*, given the observed results of higher larval mortality and growth inhibition. This suggests that *S. frugiperda* may be functionally susceptible to this hybrid, which warrants further investigation.

The AI of *S. frugiperda* varied from 9.07 in the BR008 *bmr* hybrid to 11.64 in TX635. Boregas et al. (2013), in a study evaluating the AI of *S. frugiperda* in different host plants, considered values above 10 high because this is the value found in maize plants, which is the main host of fall armyworm. The results of the present study demonstrated that the AIs were above 10 in all treatments, except for BR008 *bmr* (9.07), that was still very close to 10. This reinforces the hypothesis that the *bmr* mutation does not affect *S. frugiperda* development. In another study, Ribeiro et al. (2020) compared the effect of forage species on the development of *S. frugiperda* and found AI of 26.49 for maize, and 22.02 for *Cynodon dactylon* plants, which was the species more similar to maize. Both values were higher than those found in the present study; nevertheless, *S. frugiperda* developed well in the evaluated energy sorghum hybrids.

Dowd et al. (2016) also did not find consistency in the survival data of *S. frugiperda* in *bmr* sorghum leaves. Those authors evaluated fall armyworm survival for more than one harvest and observed a greater effect of harvest than of the *bmr* mutation. Additionally, Dowd and Satller (2015) found no differences in *S. frugiperda* mortality in *bmr* sorghum. The authors suggested the presence of the brown midrib in leaves of *bmr* sorghum may, contrary to expectations, increase the resistance of the plants, since they may be less nutritionally suitable for larvae because of this trait and possibly because of other chemical and morphological changes related to the presence of the *bmr* mutation. Our results also suggest this conclusion because although no microorganism that can digest lignin was found in the midgut of *S. frugiperda* (Dantur 2015), the *bmr* mutation had no effect on fall armyworm.

Regarding the *S. frugiperda* injury scores in sorghum hybrids in the greenhouse, no differences were observed between the *bmr* and non-*bmr* genotypes. The highest injury scores were found in the TX635 *bmr* and non-*bmr* hybrids, with maximum scores (9) observed at 14 and 21 days of larval infestation. The hybrids studied herein had the *bmr*-6 mutation, which causes reduced cinnamyl alcohol dehydrogenase activity (Oliver et al., 2005). When evaluating *bmr*-6 and *bmr*-12 sorghum hybrids, Dowd et al. (2016) did not detect consistent susceptibility to *Helicoverpa zea* (Boddie, 1850) (Lepidoptera: Noctuidae) or *S. frugiperda* in any *bmr* genotype compared to the susceptibility of the nonmutant isogenic genotypes. However, those authors reported evidence of increased resistance in the *bmr*-6 genotypes compared to the near-isogenic genotypes, and greater susceptibility of the *bmr*-12 plants to the insects both in the field and in laboratory. The results obtained by Dowd et al. (2016) differ from the results found herein, as we did not consistently find increased resistance or susceptibility of the *bmr* gene to the sugarcane borer and fall armyworm. This subject is still not resolved given the varying responses found in the literature.

Plant dry matter was highest in the BR007 non-*bmr* hybrid and lowest in the TX635 non-*bmr* hybrid. Thus, the BR007 genotype was more productive than the *bmr* genotype, which may contribute to a higher tolerance to pest infestation relative to the other two hybrids.

Conversely, the calorific value was highest in the BR008 non-*bmr* hybrid and lowest in TX635 *bmr*. This trait of higher energy content is important for energy generated from direct burning of biomass (Parrela et al., 2013).

Cellulose is the major structural component of plant cell walls; hemicellulose is the second most abundant component in lignocellulosic biomass; and lignin is the compound that gives greater rigidity to plant fibers and confers resistance to insects and pathogens. However, this trait hinders biofuel production (Dien et al., 2009; Rubin, 2008; Del Rio et al., 2007; Van Wyk, 2001). Although a reduction in lignin concentration was detected in the *bmr* genotypes, there were no differences in ADF, NDF, or hemicellulose contents, which did not differ between the *bmr* and non-*bmr* sorghum hybrids. Ebling and Kung Jr. (2004) also found no differences in the percentage of NDF or ADF between *bmr* and non-*bmr* corn, but found differences in their lignin content. These findings corroborate the results found herein, where the percentage of lignin was higher in non-*bmr* sorghum hybrids; the TX635 hybrid had the highest lignin content; and the greatest difference in lignin content was found between the *bmr* and non-*bmr* genotypes.

The parameters evaluated for *D. saccharalis* and *S. frugiperda* in our study varied between treatments, and were not consistent or predominant in only one energy sorghum hybrid or in *bmr* or non-*bmr* genotypes. From the viewpoint of integrated pest management, it is interesting that there is resistance to pests in non-*bmr* sorghum that is grown for other purposes than biomass, such as energy cogeneration through direct burning. However, for biofuel production, which is the main purpose of *bmr* sorghum plants due to its lower lignin content, the fact that it has no greater susceptibility to the main crop pests is highly important.

We can conclude that cultivation of *bmr* energy sorghum can be safe within the context of integrated pest management because it is not more susceptible to the major crop pests, sugarcane borer and fall armyworm, and regardless of whether the sorghum is *bmr* or not, control measures, using chemical and biological approaches should be applied whenever the economic thresholds are attained. Given the need to diversify the energy matrix in Brazil and worldwide since renewable energy is a key source of energy security, provides reduced dependence on fossil fuels, and causes to lesser emission of greenhouse gases, the results of this work show that cultivation of these biomass sorghum hybrids holds great promise for biofuel production.

Acknowledgments

The authors thank the Graduate Program in Entomology of the Federal University of Lavras for the scientific support to the students; Minas Gerais State Research Support Foundation (FAPEMIG) for granting a PhD scholarship to the first author; and Embrapa Corn and Sorghum for allowing this research to be carried out.

References

BARAH, A e SENGUPTA AK, 1991. Correlation and regression studies between pupal weight and fecundity of muga silkworm *Antheraea assama* Westwood (Lepidoptera: Saturniidae) on four different foodplants. *Acta Physiologica Hungarica*. vol. 78, no. 3, pp. 261 ‑264.

BOREGAS, KGB., MENDES, SM., WAQUIL, JM., FERNANDES, GAW, 2013. Estádio de adaptação de *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) em hospedeiros alternativos. *Bragantia*. vol. 72, no. 1, pp. 61‑70. https://doi.org/10.1590/S0006-87052013000100009.

BOWLING, C. C, 1967. Rearing of two lepidopterous pests of rice on common artificial diet. *Annals of the Entomological Society of America*. Vol. 60, no. 6, pp.. 1215-1216. https://doi.org/10.1093/aesa/60.6.1215.

CHERNEY, JH., CHERNEY, DJR., AKIN, DE., AXTELL, JD, 1991. Potential of brown-midrib, low-lignin mutants for improving forage quality. *Advances in Agronomy*. vol. 46, pp. 157-198. https://doi.org/10.1016/S0065-2113(08)60580-5.

CRUZ, I., 2000. Métodos de criação de agentes entomófagos de *Spodoptera frugiperda* (J.E. Smith). In: BUENO, V.H.P. (Ed.), Controle Biológico de Pragas: Produção Massal e Controle de Qualidade. Universidade Federal de Lavras, Lavras, pp. 112–114.

DANTUR, KI., ENRIQUE, R., WELIN, B., CASTAGNARO, A, 2015. Isolation of cellulolytic bacteria from the intestine of *Diatraea saccharalis* larvae and evaluation of their capacity to degrade sugarcane biomass. *AMB Express*. vol. 5, no. 15, pp. 1-11. 10.1186/s13568-015-0101-z.

DAVIS, FM., NG SS., WILLIAMS, WP, 1992. Visual rating scales for screening whorl-stage corn for resistance to fall armyworm. Mississippi Agricultural & Forestry Experiment Station. *Technical Bulletin*. vol. 186, pp. 1-9.

DEL RIO, JC., MARQUES, G., RENCORET, J., MARTINEZ, AT., GUTIERREZ, A, 2007. Occurrence of naturally acetylated lignin units. *Journal of Agricultural and Food Chemistry*. vol. 55, no. 4, pp. 5461–5468. https://doi.org/10.1021/jf0705264.

DIEN, BS., SARATH, G., PEDERSEN, JF., SATTLER, SE., CHEN, H., FUNNELL-HARRIS, DL., NICHOLS, NN., COTTA, MA, 2009. Improved Sugar Conversion and Ethanol Yield for Forage Sorghum (*Sorghum bicolor* L. Moench) lines with reduced lignin contents. *BioEnergy Research*. vol. 2, pp. 153–164. https://doi.org/10.1007/s12155-009-9041-2.

DOWD, PF., SATTLER, SE, 2015. *Helicoverpa zea* (Lepidoptera: Noctuidae) and *Spodoptera frugiperda* (Lepidoptera: Noctuidae) Responses to *Sorghum bicolor* (Poales: Poaceae) tissues from lowered lignin lines. *Journal of Insect Science*. vol. 15, no. 1 https://doi.org/10.1093/jisesa/ieu162.

DOWD, PF., FUNNELL-HARRIS, DL., SATTLER, SE, 2016. Field damage of sorghum (*Sorghum bicolor*) with reduced lignin levels by naturally occurring insect pests and pathogens. *Journal of Insect Science*. vol. 89, pp. 885-895. https://doi.org/10.1007/s10340-015-0728-1.

EBLING, TL., KUNG, L JR, 2004. Comparison of processed conventional corn silage to unprocessed and processed brown midrib corn silage on intake, digestion, and milk production by dairy cows. *Journal of Dairy Science*. vol. 87, no. 8, pp. 2519–2527. https://doi.org/10.3168/jds.S0022-0302(04)73376-7.

EMBRAPA. Empresa brasileira de pesquisa agropecuária (2013) Sistema brasileiro de classificação de solos. 3. ed. Embrapa Informação Tecnológica, Brasília, 353 p.

EPE. Empresa de Pesquisa Energética (2009) Análise de conjuntura dos biocombustíveis. Ministério de Minas e Energia, Rio de Janeiro, p. 77. https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/analise-de-conjuntura-dos-biocombustiveis. Accessed 26 June 2019.

HERNÁNDEZ, D., RIAÑO, B., COCA, M., GARCÍA-GONZÁLEZ, MC, 2015 Saccharification of carbohydrates in microalgal biomass by physical, chemical and enzymatic pre-treatments as a previous step for bioethanol production. *Chemical Engineering Journal*. vol. 262, pp. 939-945. https://doi.org/10.1016/j.cej.2014.10.049.

MAGALHÃES, PC., DURÃES, FOM, 2003. *Ecofisiologia da produção de sorgo*. Comunicado Técnico 87, Recomendações Técnicas- Sete Lagoas: Embrapa Milho e Sorgo 4p.

MAY A, 2013. Cultivo do Sorgo biomassa para a cogeração de energia elétrica. In: MAY A., SILVA DD., SANTOS FC (Eds) Documentos 152. Embrapa Milho e Sorgo, Sete Lagoas-MG, pp69.

MENDES, SM., BOREGAS, KGB., LOPES, ME., WAQUIL, MS., WAQUIL, JM, 2011. Respostas da lagarta-do-cartucho a milho geneticamente modificado expressando a toxina Cry 1Ab. *Pesquisa agropecuária brasileira*. vol. 46, no. 3, pp. 239-244 https://doi.org/10.1590/S0100-204X2011000300003.

MENDES, SM., WAQUIL, JM., RODRIGUES, JAS., SAMPAIO, MV., VIANA, PA, 2014. *Manejo de pragas na cultura do sorgo*. Informe agropecuário 1:76-88.

OLIVER, AL., PEDERSEN, JF., GRANT, RJ., KLOPFENSTEIN, TJ, 2005. Comparative effects of the sorghum *bmr*-6 and *bmr*-12 genes: I. Forage Sorghum Yield and Quality. *Crop Science*. vol. 45, no. 6, pp. 2234-2239. https://doi.org/10.2135/cropsci2004.0644.

PARRELLA, RAC, 2013. *Cultivo do sorgo biomassa para a cogeração de energia elétrica*. In: MAY A, SILVA D. D, SANTOS FC. Documentos 152, Embrapa Milho e Sorgo, Sete Lagoas-MG, pp 69.

PENCOE, NL., MARTIN, PB, 1982. Fall armyworm (Lepidoptera: Noctuidae) larval development and adult fecundity on five grass hosts. *Environmental Entomology*. vol. 11, no. 3, pp. 720-724. https://doi.org/10.1093/ee/11.3.720.

R CORE TEAM, 2019. R: A language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria. p. 85. URL https://www.R-project.org/

REDDY, Y. R. BLUMMEL, M, 2020. Options for Enhancing Sorghum Forage Utilization in Ruminants. In: Tonapi V.A., Talwar H.S., Are A.K., Bhat B.V., Reddy C.R., Dalton T.J. (eds) Sorghum in the 21st Century: Food – Fodder – Feed – Fuel for a Rapidly Changing World. Springer, Singapore. https://doi.org/10.1007/978-981-15-8249-3_26.

RIBEIRO, LP., KLOCK, ALS., NESI, CN., LUCZKIEVICZ, FRG., TRAVI, MRL., RECH, AF, 2020. Adaptability and comparative biology of Fall Armyworm on maize and perennial forage species and relation with chemical-bromatological composition. *Neotropical Entomology*. vol. 49, pp. 758–767. DOI:10.1007/s13744-020-00794-7.

ROBERTSON, JB., VAN SOEST, PJ., 1981. The detergent system of analysis and its application to humam foods. In: JAMES WPT, THEANDER O (Eds) *The analysis of dietary fiber in food*, Marcel Dekker, New York, pp. p123–158.

RUBIN, EM., 2008. Genomics of cellulosic biofuels. *Nature*. vol. 454, pp. 841–845. https://doi.org/10.1038/nature07190

SANTOS, RCS., CARNEIRO, ACO., CASTRO, AFM., CASTRO, RVO., BIANCHE, JJ., SOUZA MM., CARDOSO, MT, 2011. Correlações entre os parâmetros de qualidade da madeira e do carvão vegetal de clones de eucalipto. *Scientia Forestalis*. vol. 39, no. 90, pp. 221-230.

SILVA, TI., SANTANA, LD., CAMARA, FT., PINTO, AA., BRITO, LLM., MOTA AMD., 2017. Produtividade de variedades de sorgo em diferentes arranjos populacionais em primeiro corte e rebrota. *Revista Espacios*. vol. 38, no. 27, pp. 16-27.

SOUZA, CSF., SILVEIRA, SCP., PITTA, RM., WAQUIL, JM., PEREIRA, EJG., MENDES, SM, 2019. Response of field populations and Cry-resistant strains of fall armyworm to Bt maize hybrids and Bt-based bioinsecticides. *Crop protection*. vol. 120, pp.1-6. https://doi.org/10.1016/j.cropro.2019.01.001.

SYSTAT SOFTWARE INC.-SSI. Sigmaplot for windows, version 10. 2006. Disponível em http://www.systat.com/prodcts/sigmaplot/. Acesso em 01 Feb. 2021.

VAN WYK, JP., 2001. Biotechnology and the utilization of biowaste as a resource for bioproduct development. *Trends Biotechnology*. vol. 19, no. 5, pp. 172–177. https://doi.org/10.1016/S0167-7799(01)01601-8.

VENDRAMIM, JD., GUZZO, EC, 2009. Resistência de plantas e a bioecologia e nutrição dos insetos. In: PANIZZI AR, PARRA JRP (Eds). *Bioecologia e nutrição de insetos: base para o manejo integrado de pragas*. Embrapa Informação Tecnológica, Brasília, DF, pp 1055-1105.

VENDRAMIM, JD., GUZZO, EC., RIBEIRO, LP. Antibiose. In: BALDIN, E. L. L.; VENDRAMIM, JD., LOURENÇÃO, AL. (eds). *Resistência de plantas a insetos- Fundamentos e Aplicações*. Piracicaba, São Paulo, Brasil: Fealq, 2019. p. 185-214.

VENDRUSCOLO, TPS., BARELLI, TMAA., CASTRILLON, MAS., SILVA, RS., OLIVEIRA, FT., CORRÊA, CL., ZAGO, BW., TARDIN, FD, 2016. Correlation and path analysis of biomass sorghum production. *Genetics and Molecular Research*. vol. 15 no. 4, pp. 1-10. 10.4238/gmr15049086.

ZEGADA-LIZARAZU, W., Monti, A, 2012. Are we ready to cultivate sweet sorghum as a bioenergy feedstock? A review on field management practices. *Biomass Bioenergy*. Vol 40, p. 1–12. https://doi.org/10.1016/j.biombioe.2012.01.048.

Table 1 Means (± SE) of larval survival (%) and larval biomass (mg) at 10 days of *Diatraea saccharalis* in *bmr* and conventional non-*bmr* near-isogenic hybrids

Hybrids	**Survival**	**Biomass at 10 days***
TX635	95.83 ± 3.14 a	12.22 ± 0.52 c
TX635 *bmr*	98.95 ± 1.04 a	19.77 ± 0.80 a
BR007	96.87 ± 2.19 a	14.71 ± 0.98 c
BR007 *bmr*	98.95 ± 1.04 a	15.40 ± 0.41 bc
BR008	93.74 ± 2.61 a	14.92 ± 1.08 c
BR008 *bmr*	98.95 ± 1.04 a	18.68 ± 0.98 ab

Means followed by different letters in the same column are different by Tukey's test ($P < 0.05$).

Table 2 Means (± SE) of plant height (cm), total number of internodes, number of healthy and bored internodes, gallery length and diameter (cm), and survival (%) and biomass (mg) of *Diatraea saccharalis* pupae in *bmr* sorghum hybrids and non-*bmr* near-isogenic genotypes

VARIABLES	HYBRID	*Bmr*	non-*bmr*
Plant height (cm)	TX635	17.91 ± 2.42 a	19.31 ± 1.70 a
	BR007	22.09 ± 2.04 a	23.44 ± 2.22 a
	BR008	22.88 ± 1.93 a	22.97 ± 1.98 a
Total internodes (nº)	TX635	4.43 ± 0.28 a	4.82 ± 0.25 a
	BR007	5.23 ± 0.31 a	5.42 ± 0.44 a
	BR008	5.20 ± 0.36 a	5.22 ± 0.32 a
Healthy internodes (nº)	TX635	3.43 ± 0.29 a	3.78 ± 0.25 a
	BR007	4.00 ± 0.26 a	4.43 ± 0.35 a
	BR008	3.93 ± 0.32 a	3.98 ± 0.32 a
Bored internodes (nº)	TX635	1.00 ± 0.28 a	1.03 ± 0.25 a
	BR007	1.23 ± 0.31 a	0.98 ± 0.44 a
	BR008	1.27 ± 0.36 a	1.23 ± 0.32 a
Gallery length (cm)	TX635	2.77 ± 0.60 a	2.60 ± 0.49 a
	BR007	2.66 ± 0.48 a	1.88 ± 0.48 a
	BR008	2.67 ± 0.59 a	2.89 ± 0.52 a
Gallery diameter (cm)	TX635	0.27 ± 0.04 a	0.38 ± 0.09 a
	BR007	0.29 ± 0.04 a	0.32 ± 0.04 a
	BR008	0.33 ± 0.04 a	0.31 ± 0.04 a
Survival (%)	TX635	52.78 ± 0.88 b	51.67 ± 0.79 b
	BR007	58.75 ± 2.08 a	59.12 ± 1.43 a
	BR008	51.25 ± 1.08 b	49.86 ± 1.04 b
Pupal biomass (mg)	TX635	133.73 ± 1.58 ab	135.67 ± 2.26 a
	BR007	125.55 ± 3.18 ab	111.04 ± 2.49 c
	BR008	123.99 ± 3.28 b	131.94 ± 2.74 ab

Means followed by different letters in the same column differ according to Tukey's test ($P < 0.05$).

Table 3 Means (± SE) of variables of the bromatological analysis of *bmr* and non-*bmr* sorghum hybrids

VARIABLE	HYBRID	*Bmr*	non-*bmr*
Dry matter 65 °C (MG ha^{-1})	TX635	14.23 ± 0.03 ab	11.48 ± 0.80 b
	BR007	14.13 ± 0.46 ab	17.42 ± 2.11 a
	BR008	12.87 ± 1.25 ab	15.05 ± 0.93 ab
ADF (%)	TX635	35.28 ± 0.91 a	37.92 ± 0.96 a
	BR007	33.88 ± 2.13 a	36.65 ± 3.06 a
	BR008	34.74 ± 2.20 a	35.46 ± 3.35 a
NDF (%)	TX635	58.93 ± 0.92 a	63.96 ± 1.42 a
	BR007	58.60 ± 2.50 a	60.89 ± 3.69 a
	BR008	59.86 ± 0.30 a	60.50 ± 3.12 a
Lignin (%)	TX635	3.24 ± 0.08 c	4.79 ± 0.20 a
	BR007	3.21 ± 0.07 c	3.89 ± 0.12 b
	BR008	3.26 ± 0.18 c	4.64 ± 0.37 a
Hemicellulose (%)	TX635	24.75 ± 0.53 a	26.04 ± 0.92
	BR007	25.27 ± 0.74 a	24.69 ± 0.79
	BR008	25.54 ± 0.41 a	25.78 ± 0.74
Calorific value (MJ/kg)	TX635	16.49 ± 0.08 b	16.71 ± 0.17 ab
	BR007	16.73 ± 0.23 ab	16.61 ± 0.14 ab
	BR008	16.71 ± 0.22 ab	17.03 ± 0.05 a

Means followed by different letters in the same column differ according to Tukey's test ($P < 0.05$).

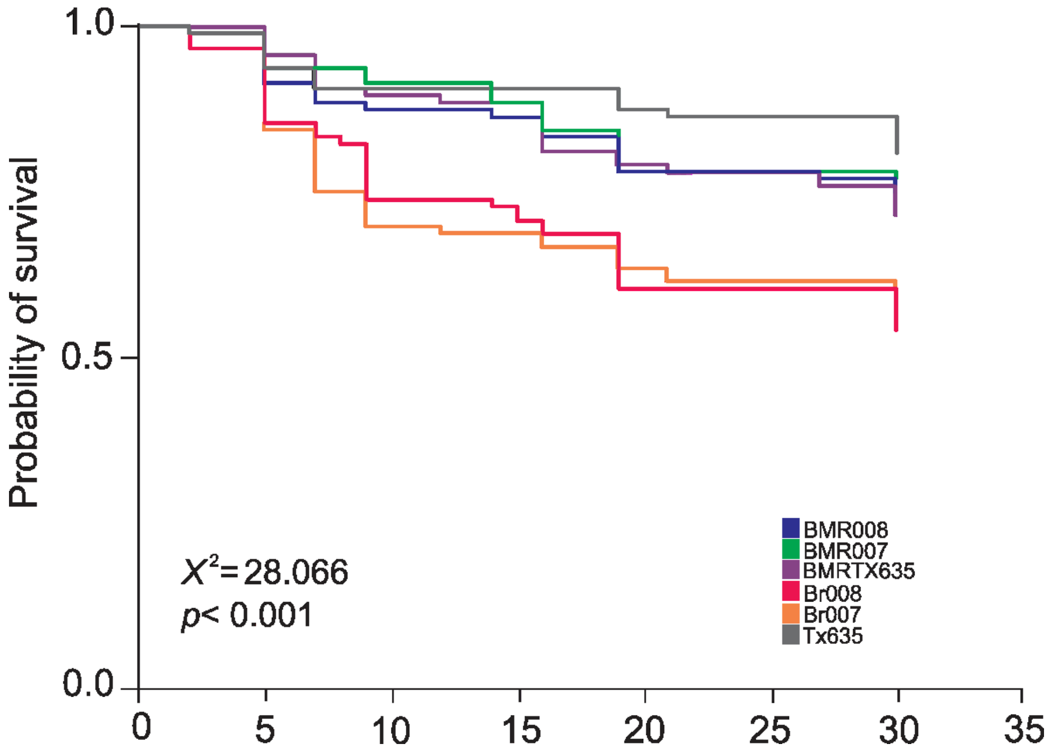

Fig 1 Survival curve of *Spodoptera frugiperda* as a function of days of development in *bmr* sorghum hybrids and their respective conventional non-*bmr* isogenic genotypes.

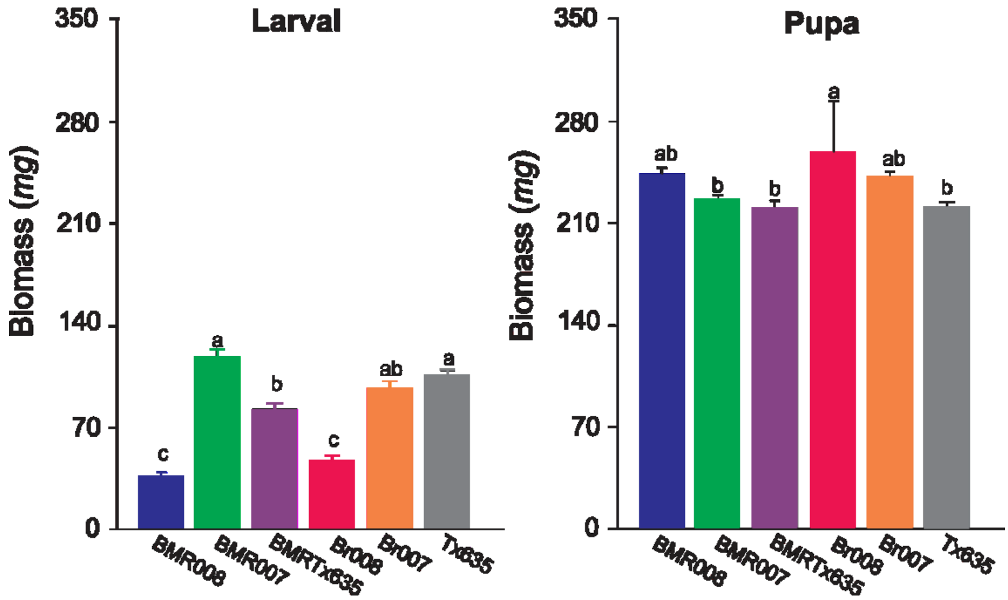

Fig 2 Response of *Spodoptera frugiperda* feeding on leaves of *bmr* sorghum hybrids and their respective isogenic genotypes: larval biomass (mg) and pupal biomass (mg). Data are means and standard errors. Means followed by different letters differ according to Tukey's test (P < 0.05).

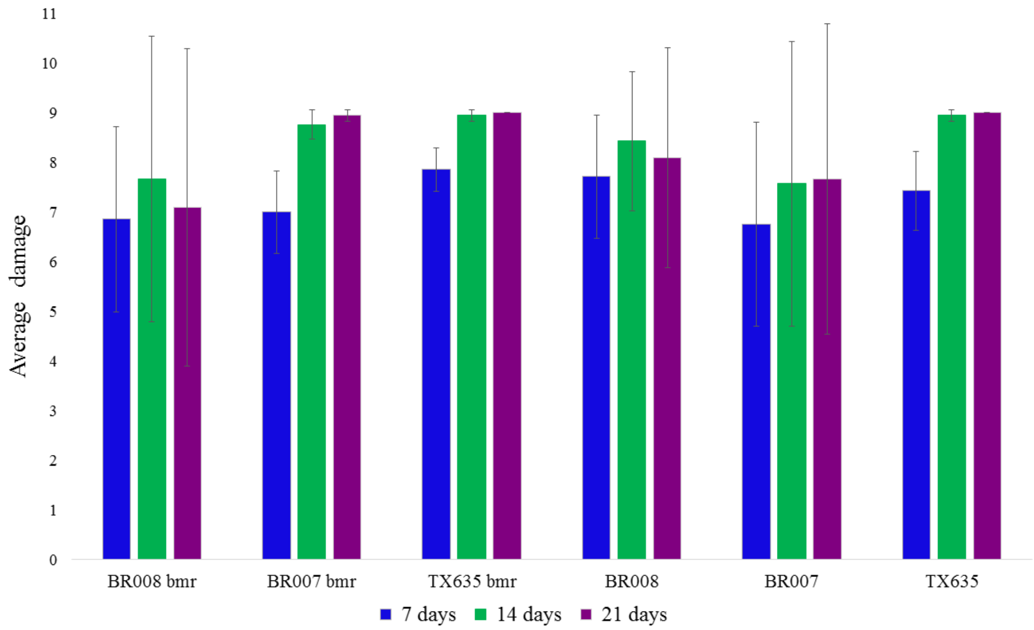

Fig 3 Injury scale (0-9) for *Spodoptera frugiperda* at 7, 14, and 21 days after infestation by recently hatched larvae in the different hybrids of *bmr* sorghum and their respective conventional isogenic genotypes. Intervals between adjacent bars do not differ from one another by the confidence interval (P < 0.05).

ARTICLE 2- What is the potential of the sugarcane borer in reducing sorghum grain production?

Camila da Silva Fernandes Souza[1]., Bruno Henrique Sardinha de Souza[1]., Josélia Carvalho Oliveira França[1]., Cícero Bezerra de Menezes[2] Priscilla Tavares Nascimento[1]., & Simone Martins Mendes[2]*

[1] Departament of Entomology, Universidade Federal de Lavras, Campus Universitário, Lavras, MG, Brazil.

[2]Embrapa Milho e Sorgo, Sete Lagoas, MG, Brazil.

*Author for correspondence:

Dr. Simone Martins Mendes

Embrapa Milho e Sorgo

Rodovia MG 424, Km 45, P.O. Box 285, Sete Lagoas, MG, 35701-970, Brazil,

E-mail: simone.mendes@embrapa.br

Preparado segundo a norma e submetido à "NEOTROPICAL ENTOMOLOGY"

Orcid number:

Souza CSF: https://orcid.org/0000-0002-2740-9223

Souza BHS: https://orcid.org/0000-0002-2802-2688

França, JCO: https://orcid.org/0000-0002-8515-2120

Menezes CB: https://orcid.org/0000-0001-9437-6946

Nascimento PT: https://orcid.org/0000-0003-4366-4918

Mendes SM: https://orcid.org/0000-0002-9773-9017

Abstract

Pest attack is an important factor in the loss of sorghum productivity, and one of the main pests of grain sorghum is *Diatraea sacharalis*. Thus, the objective of this paper was to evaluate the influence of *D. sacharalis* infestation on grain production in commercial sorghum hybrids. For this, grain sorghum hybrids were planted in three crops seasons: March 2018 (2018/1) (CROP SEASON 1), September 2018 (2018/2) (CROP SEASON 2) and March 2019 (2019/1) (CROP SEASON 3). Six treatments were used in the experiment, the three hybrids of grain sorghum and the same three hybrids with chemical treatment using the product Altacor® (150 ml ha^{-1}), under natural infestation, in four replications. The parameters evaluated were: length of galleries (cm), plant height (cm), length (cm) and weight (g) of panicles, infestation intensity and productivity. The intensity of infestation in the three crops season was higher when not treated with insecticide and consequently resulted in lower productivity. Regarding the difference between seasons, the 1st season planting had lower infestation intensity. The hybrid DKB 590 had the lowest tolerance level, whereby with insecticide treatment production increased 1.5 times in crop season 1 (149.77 %). In crop season 2, hybrid BRS 373 exhibitedthe lowest increase in grain yield with control (29.79%), followed by AG1090 with 33.13%, and again DKB 590 (40.79%) with greater dependence on chemical control to increase yield. Crop season 3 obtained the lowest yield among the three crops, and hybrid AG1090 responded better to chemical control with, yield increase of 105.90%, which is equivalent to more than double the yield when using chemical control, followed by DKB 590 with 54.26% which indicates more than half of the increase in production, and BRS 373 with 38.19%. This is the first study that effectively shows how much grain loss occurs by *D. saccharalis* attack in grain sorghum. The sugarcane borer was able to cause yield loss up to 1.5x when sorghum plants were not controlled by insecticide treatment in the less tolerant hybrid, and 50% in the more productive and tolerant hybrid.

Keywords: Infestation intensity; *Diatraea saccharalis*; yield. IPM

Introduction

Sorghum (*Sorghum bicolor* [L.] Moench) is an important cereal crop used as grain, forage, and energy. Grain sorghum make up 40-60% in monogastric animal feed, and has potential to replace corn in ruminant feed in the future and as it has 95% of the biological value of corn and has lower cost, which can reach 15-45% less than corn (Waquil et al. 2003; Miranda et al. 2015; Carvalho 2020). Grain sorghum is also one of the main sources of energy, proteins, vitamins, and minerals for millions of people in semiarid regions of Africa and Asia (Fao 1995; Queiroz et al. 2015). Sorghum flour can replace wheat flour in food preparation, such as bread, cakes, and pasta; due to the fact that it has advantageous characteristics such as neutral taste, light color, and does not contain gluten, sorghum flour has great potential to be used in the preparation of food products for celiac individuals (Ciacci et al. 2007).

Brazil stands out as the 9th producer of grain sorghum in the world, contributing ~10% of worldwide production (IBGE, 2020). In the 2019 crop season, nearly 2.5 million tons of sorghum grains were produced in Brazil, with the state of Goiás being the largest producer of the cereal, and responsible for 42.8% of total national production, followed by the state of Minas Gerais. The attack of pest insects is an important biotic factor affecting yield losses in sorghum crop, reducing its potential for grain production. Thus, studying the behavioral patterns of pest insect infestation in their host plants is necessary to understand insect preference and choice for the host plant, the respective plant response to pest injury, and ultimately the effects on crop production (Knolhoff and Heckel, 2013).

The sugarcane borer *Diatraea saccharalis* (Fabricius) (Lepidoptera: Crambidae) is the a primary pest main pest of sugarcane and is very harmful to other important crops such as corn, sorghum, and rice. In sorghum, *D. saccharalis* is a problem not only in Brazil, but also in other regions of South America, Central America, the Caribbean, and South of USA, and among the Lepidoptera it is considered the primary pest most important pest (Fabricius, 1794) (Lepidoptera: Crambidae) (Legaspi et al. 1997; Hayden 2012; Mendes et al. 2014; Grimi et al. 2018).

The galleries caused by *D. saccharalis* larvae in the plant stem make this plant structure weakened, rendering the plants more vulnerable to other environmental factors. The attack of *D. saccharalis* causes stem rot by favoring the entry of pathogenic microorganisms, hindering photoassimilates translocation, shortening the stalk internodes and toppling, and overall weakening the plant. In some regions of Brazil, the damage by *D. saccharalis* may correspond to 30% of total grain production. *D. saccharalis* is a harder to detect pest, and farmers can only see the losses when it is too late, because they do not usually monitor the population of this insect species in the field (Mendes et al. 2012, 2014; Silva et al. 2014; Araujo 2017).

Within an integrated pest management approach, it is very important to use different control tactics for the control of key pests in sorghum crops, such as *D. saccharalis* in order to reduce the damage caused to grain production (Mendes et al. 2014; Vilela et al. 2016). Plant resistance is one of the tactics recommended within the IPM precepts, since it presents as one of the main advantages its compatible integration with other control methods. Plants naturally possess differences in terms of susceptibility to insect pests, that is, a phenotype can present greater or lesser resistance to pest attack, which can be expressed in a constitutive or induced manner (Lara 1991; Gatehouse 2002; Bastos et al. 2015; Armstrong et al. 2016).

For sugarcane, the level of economic damage is 3% of infestation intensity; however, an infestation intensity of 1% can cause yield reductions of up to 0.28% in alcohol production, 0.49% in sugar production, and 1.5% in stalks production (Arrigoni 2002). In sorghum that is more resistant to the borer compared to sugarcane, an economic injury level of 4% borer infestation can be used (Vilela et al. 2014). In our study, the reason for choosing the tested hybrids was that AG1090, DKB 590, and BRS373 belong to the main seed producing companies in Brazil, and also because these hybrids were among the most planted in the 2017/2018 crop season (Menezes et al. 2018). However, to the best of our knowledge, there is no information about borer-resistance levels in these hybrids.

Due to the feeding behavior in making galleries in plant stem, *D. saccharalis* larvae are protected within this structure, hindering the action of chemical control. Despite this cryptic behavior, it is often the method most used by farmers for borer control due to its practicality and culture of use. The number of insecticide active ingredients registered for use in sorghum crop in Brazil is very restrict, in which only three molecules and four commercial products are available: spinetoram, alpha-cypermethrin, and teflubenzuron (Agrofit 2021). In the present paper, the insecticide chlorantraniliprole (commercial product Altacor®) was chosen for use against *D. saccharalis*; although it not registered for sorghum, it is a product successfully used for borer control in sugarcane that is the main host plant of the pest, and studies are lacking for evaluation of borer control in the sorghum crop (Oliveira et al. 2020; Souza et al. 2020).

In grain sorghum there are no records of yield losses in face of sugarcane borer attack. This is the first study that deals with yield loss estimate in function of borer injury intensity. Thus, the objective of this work was to evaluate sugarcane borer damage potential in three of the most used commercial sorghum hybrids, as well as how they vary in resistance levels to borer injury.

Materials and Methods

Experimental site and conditions

The study was conducted in an experimental field at Embrapa Milho e Sorgo, in Sete Lagoas, MG, Brazil. The region is at 772m above sea level, and the climate in Sete Lagoas is tropical. According to Köppen's classification, the climate is classified as Aw. 21.5 °C (average temperature), and 1279 mm is the average annual rainfall. The Embrapa research institution is located at 19º28'S, 44º15'08''W, and 732 m. The soil in the region is of the red yellow latosol type, with medium texture and silty (Embrapa, 2013). As the region of Sete Lagoas has a history of high natural infestation of *D. saccharalis* (VIlela et al. 2017), it was not necessary to carry out artificial infestation in sorghum plants.

Experiment conditions

The experiment was carried out in three consecutive crop seasons in the same experimental area: March 2018 (2018/1) (CROP SEASON 1) (winter season), September 2018 (2018/2) (CROP SEASON 2) (summer season) and March 2019 (2019/1) (CROP SEASON 3) (winter season). The soil was fertilized with 400 kg ha^{-1} of NPK 8-28-16. At 20 days after germination, cover fertilization was performed using 200 kg ha^{-1} of urea. Weed control was carried out using atrazine-based herbicide, at a dose of 1.5 kg a.i. per hectare. Cultural practices were performed according to May et al. (2014). The sorghum hybrids used in the experiment were AG1090, BRS373 and DKB590; these hybrids were chosen because they belong to the main seed producing companies in the country and were the most planted in recent crop seasons (Menezes et al., 2018).

Plant thinning was done 15 days after germination, leaving 10 plants per row meter, for a total of 50 plants per row in the plots. The experiment was designed in complete randomized blocks. Each experimental plot consisted of six rows with 5 m in length and 0.7 m in spacing. In total, four blocks were used as replicates and six treatments were evaluated, consisting of three grain sorghum hybrids with and without chemical control with the insecticide chlorantraniliprole (Altacor®, FMC Química do Brasil LTDA, Campinas, SP, Brazil) at the dose recommended by the manufacturer of 150 ml ha^{-1}. The insecticide was applied at the beginning of plant development, in three applications in total; the first application took place 15 days after plant germination, and the other two applications were spaced every 10 days.

Evaluation of *D. saccharalis* injury and production of sorghum hybrids

At the beginning of plant maturation phase, panicles on the three central rows of the plots were bagged to prevent bird attacks. These rows were then harvested at the end of grain maturation for evaluation of yield parameters.

The plants were cut close to the ground at harvest (~120 days after germination) and were longitudinally opened to detect and quantify injury by *D. saccharalis* larvae. The parameters evaluated were: the length of galleries (cm), plant height (cm), infestation intensity (%), and yield (kg ha^{-1}). Infestation intensity (I.I.) of sugarcane borer was calculated according to the formula: I.I. (%) = number of bored internodes /total number of internodes x 100. The weight (g) of panicles was determined on a scale with sensitivity of hundredths of a gram, and plant height was measured with a ruler (cm). Through the weight of grains and determination of the moisture content of the grains in each plot, yield was estimated in kg ha^{-1}, using the formula: Mc = (100 - Ui) x Mi/100 - Ui. Where: Mc = corrected mass; Ui = initial humidity degree; Mi = initial mass; Uc = degree of humidity correction (13%).

Statistical analysis

Data obtained in the three crop seasons were submitted to the Shapiro-Wilk test to check for normality of errors and to the Bartlett test for homogeneity of variances. As data did not follow a normal distribution or exhibited heterogeneity of variances, they were analyzed using generalized linear models (GLM) with Quasi Poisson distribution, and the means of treatments were compared by Tukey's test (α=0.05). Pearson correlation analysis was performed on data of infestation intensity and yield. The analyses were performed using the statistical R software version 3.5.3 (R Development Core Team 2019).

Results

The results indicated significant differences both between sorghum hybrids and in hybrids treated and not with insecticide (Figure 1). Crop seasons were analyzed separately, but were plotted in the same figure for easier visualization of results. The hybrids treated with insecticide in the three crop seasons showed greater plant height, smaller size of gallery by *D. saccharalis* larvae, and greater panicle length and weight (Figure 1). The hybrid AG1090 had no difference in plant height when treated or not with insecticide in crop season 1, while the other hybrids had lower height when not treated with insecticide (F= 13.34, df= 5, P<0.001). In crop season 2, hybrid BRS373 had the lowest plant height both with insecticide and without application (F= 45.54, df= 5, P<0.001). In crop season 3, the three hybrids had higher plant heights when treated with insecticide; in addition, hybrid BRS 373 without insecticide was the hybrid with the lowest height of plants (F= 54.91, df= 5; P<0.001) (Figure 1).

The size of bored galleries in the three crop seasons was higher when sorghum hybrids were not treated with insecticide. In crop season 1 (F= 11.58, df= 5, P<0.001) e 3 (F= 15.09, df= 5; P<0.001) hybrids BRS373, AG1090, and DKB 590 had smaller gallery sizes in this order when treated with insecticide. In crop season 2, the three hybrids treated with insecticide showed smaller gallery size than untreated plants, but the hybrids did not differ (F= 15.62, df= 5, P<0.001) (Figure 1).

Panicles size were greater when the hybrids when treated with insecticide. In crop season 1, insecticide-treated hybrids did not differ, showing larger panicle size than untreated plants that presented smaller panicles size (F= 17.58, df= 5, P<0.001). In crop season 2, the hybrid AG1090 showed the highest plant height followed by hybrids DKB590 and BRS 373 when treated with insecticide (F= 9.82, df= 5, P<0.001). In crop season 3, the hybrids DKB 590 and BRS 373 had the smallest panicles size when not treated with insecticide (F= 13.24, df= 5, P<0.001) (Figure 1).

In relation to panicles weight, in crop seasons 1 (F= 42.24, df= 5, P<0.001) and 3 (F= 24.26, df= 5, P<0.001), hybrid AG 1090 exhibited greater mean values when treated with insecticide, while DKB 590 and BRS 373 had the lowest panicles weight without insecticide. In crop season 3, the three hybrids treated with insecticide had higher panicles weight, while the lowest weight was obtained in hybrid BRS 373 without insecticide (F= 13.50, df= 5, P<0.001) (Figure 1).

The infestation intensity of *D. saccharalis* in the evaluated three crop seasons was higher when the hybrids were not treated with insecticide, and consequently resulted in lower grain yields. In all treatments across evaluated crop seasons, the higher the borer infestation intensity, the lower the grain production, indicated by the significant negative correlation of Pearson's analysis, that is, the parameters were inversely proportional. Crop season 2 exhibited the strongest significant correlation (r=-0.85), followed by crop season 3 (r=-0.67), and crop season 1 (r=-0.65) (Figure 2).

Discussion

The results of the natural infestation observed in the stalks of grain sorghum hybrids demonstrated that *D. saccharalis* has a significant negative effect on grain yield. The hybrids with insecticide aplicationhad product smaller gallery size of *D. saccharalis*, higher plant height, larger panicle length and weight, and consequently higher grain yield than non treated hybrids plots. This demonstrates that chemical control is efficient when insecticide is applied at the beginning of sorghum plant development (stages V3-V4) (Magalhães and Durães 2003). It shows that greater care is needed at the beginning of plant production. However, it is recommended that monitoring be continued throughout the crop cycle as these results are on specific hybrids grown in a specific production region.

Although positive results in the three crop seasons for the hybrids with insecticide applications and decreasing borer infestation intensity, crop season 3 (winter season) was the one with the highest pest infestation intensity and lowest grain yield. Thus, if the number of applications were increased, the infestation intensity would decrease. Likewise, crop season 2 (summer season) was the one with the lowest infestation intensity and higher grain production, which could probably be maintained with a lower number of insecticide applications as productivity would still be high.

Ccorrelation was inversely proportional, i.e., as borer infestation intensity decreased, grain yield increased proportionally in three crop seasons. Infestation intensity is an important index and the most used parameter to assess sorghum resistance to *D. saccharalis*. The 1st crop season showed mean borer infestation rate of 12.11% in the hybrid BRS373 without insecticide treatment, which is equivalent to twice that found by Lara et al. (1997) evaluating *D. saccharalis* infestation in sorghum, who also found greater infestation intensity in the 2nd season planting, which was about 3x lower than that found in the plants without chlorantraniliprole treatment in the present study. This shows the potential of the pest for sorghum, which is considered silent due to its cryptic behavior, as the farmers usually do not monitor the borer field populations, and this insect goes unnoticed in the crops.

In another study evaluating sorghum resistance to *D. saccharalis* in the same, Waquil et al. (2001) found an infestation rate of *D. saccharalis* of more than 75% in commercial sorghum hybrids, and almost 100% in sorghum lines. This shows how the infestation rate vary between sorghum genotypes, and how it is important to know these results for recommending hybrid for farmers whose crops have high *D. saccharalis* infestations. Lahiri et al. (2019) showed potential for combining host plant resistance and chemical control for *Melanaphis sacchari* (Zethner, 1897) (Hemiptera: Aphididae), and this management strategy could also be effective against *D. saccharalis*, meriting future evaluation.

The level of control of *D. saccharalis* in sugarcane crops varies from 3-5% infestation intensity, depending on the production costs and economic revenue. Considering that grain sorghum is more tolerant to *D. saccharalis* attack than sugarcane, a control level of 4% infestation intensity or four weekly adults/trap (Vilela et al. 2014). However, these authors worked with sweet sorghum where the potential for yield reduction is directly in the stalk. Here, we also highlight the potential of borers in the grain. However, common sense should always be used in control decision-making; for example, even with the application of insecticide in the present study, there were moderate infestation intensity levels and still was possible to achieve high production of the than in the insecticide free condition.

In a study carried out with sugarcane, sugar sorghum, and biomass sorghum, the impact of *D. saccharalis* on production parameters were evaluated and there was a negative relationship between infestation intensity and ethanol production, reducing by up to 13% in high pest infestations (Wilson et al. 2018). In a study with corn, to the authors estimated that the plants yielded an average of 2.51 g of grains for each internode bored by *D. saccharalis*, which is equivalent to 2.03% yield loss per plant for each internode attacked; these values can be considered a significant loss if the infestation is high (Serra and Trumper 2020).

In general, the results of our study using commonly planted commercial hybrids showed sorghum susceptibility to sugarcane borer under high infestation rates, causing substantial yield losses in all hybrids when not treated with insecticide. Therefore, depending on the pest population density in the field, *D. saccharalis* can be considered one of the main pests of grain sorghum crop.

According to our results, taken together we can infer that the three sorghum hybrids behaved better in first-season planting (summer season) which had the strongest significant correlation (r = -0.85) between borer infestation intensity and yield. In crop season 1, hybrid AG1090 showed a higher tolerance level, i.e., even without chemical control the grain yield was higher; compared to the other hybrids, it had greater plant height and produced more; and among the hybrids, it presented the lowest increase (40.54%) in grain yield when insecticide treated, followed by BRS373 with 48.94% yield increase with chemical control in crop season 1.

The hybrid DKB 590 had the lowest tolerance level, whereby with insecticide treatment production increased 1.5 times in crop season 1 (149.77 %). In crop season 2, hybrid BRS 373 exhibitedthe lowest increase in grain yield with control (29.79%), followed by AG1090 with 33.13%, and again DKB 590 (40.79%) with greater dependence on chemical control to increase yield. Crop season 3 obtained the lowest yield among the three crops, and hybrid AG1090 responded better to chemical control with, yield increase of 105.90%, which is equivalent to more than double the yield when using chemical control, followed by DKB 590 with 54.26% which indicates more than half of the increase in production, and BRS 373 with 38.19%. Tolerant genotypes produce more than less tolerant plants, which can raise the economic injury level for insect pest, reducing the number of insecticide applications, and consequently lower selection pressure on the pest (Koch et al. 2019). In grain sorghum, so far there are no records of effective losses in relation to sugarcane borer infestation.

This is the first study that effectively shows how much grain loss occurs by *D. saccharalis* attack in grain sorghum. The sugarcane borer was able to cause yield loss up to 1.5x when sorghum plants were not controlled by insecticide treatment in the less tolerant hybrid, and 50% in the more productive and tolerant hybrid. However, it is worth noting that our results show how the same hybrid in the same growing region can behave very differently in relation to tolerance and productivity, and all these factors can change the recommendation of the most suitable hybrid for a particular insect pest, region, and planting season.

Declarations

Funding: Minas Gerais State Research Support Foundation (FAPEMIG) for granting a PhD scholarship to the first author and Embrapa Milho e Sorgo for allowing this research to be carried out

Conflicts of interest/Competing interests: No conflict of interest

Availability of data and material: Not applicable

Code availability: Not applicable

Ethics approval: Not applicable

Consent to participate: Not applicable

Consent for publication: All authors participated and are in agreement with this publication.

Authors' contribution: Camila S F. Souza performed the methodology of the essays and wrote the manuscript, Bruno H. S Souza, Priscilla T Nascimento and Simone M Mendes helped with the writing of the manuscript; Joselia C O França performed the statistical analysis of the data and graphics, Cícero B Menezes donated the seeds of the hybrids to carry out the essay and helped with the writing of the manuscript.

Acknowledgments

The authors thank the Graduate Program in Entomology of the Federal University of Lavras for the scientific support to the students; Minas Gerais State Research Support Foundation (FAPEMIG) for granting a PhD scholarship to the first author; and Embrapa Corn and Sorghum for allowing this research to be carried out.

References

AGROFIT- Sistema de Agrotóxicos Fitossanitários. Brasília, 2020. Disponível em: <http://extranet.agricultura.gov.br/agrofit_cons/principal_agrofit_cons> Acesso em 26 de janeiro de 2021.

Arrigoni EB (2002). Broca da cana: importância econômica e situação atual. In Pragas da cana-de-açúcar: importância econômica e enfoques atuais. Edited by Arrigoni EB, Dinardo-Miranda LL, Rossetto R STAB/IAC/CTC Piracicaba, São Paulo, Brazil. pp. 1-4.

Bastos CS, Ribeiro AV, Suinaga FA, Brito SM, Oliveira AAS, Barbosa TM, Santos P de J dos, Oliveira DVV, Teichmann YSK (2015) Resistência de plantas a insetos: contextualização e inserção no MIP. In: Visotto LE, Fernades FL, Carvalho Filho A, Lopes EA, Aquino LA de, God PIVG, Ruas RAA, Sousa Junior JM de (Eds). Avanços tecnológicos aplicados à pesquisa na produção vegetal. Viçosa: UFV. p.32-72.

Carvalho R, Dias RC (2020). Milho ou Sorgo na Safrinha, Qual a melhor decisão? Informativo Agroservice KWS, 2p.

Ciacci C, Maiuri L, Caporaso N, Bucci C, Del Giudice L, Rita Massardo D, Pontieri P, Di Fonzo N, Bean SR, Ioerger B, Londei M (2007) Celiac disease: in vitro and in vivo safety and palatability of wheatfree sorghum food products. Clin. Nutr 26: 799- 805. doi: 10.1016/j.clnu.2007.05.006

Embrapa (2013) Empresa Brasileira de Pesquisa Agropecuária. Sistema brasileiro de classificação de solos. 3. ed. Embrapa Informação Tecnológica, Brasília, 353 p.

Food and Agricultural Organization (FAO) (1995) Sorghum and millets in human nutrition. FAO Food and Nutrition Series, 27. ISBN 92-5-103381-1.

Gatehouse JA (2002) Plant resistance towards insect herbivores: a dynamic interaction. New Phytologist 156: 145-169. https://doi.org/10.1046/j.1469-8137.2002.00519.x

Grimi DA, Parady B, Ramos ML, Machado M, Ocampo F, Willse A, Martinelli S, Head G (2018) Field-evolved resistance to Bt maize insugarcane borer (*Diatraea saccharalis*) inArgentina. Pest Manag Sci 74: 905-913. https://doi.org/10.1002/ps.4783

Hayden JE (2012) Mexican rice borer, *Eoreuma loftini* (Dyar) (Lepidoptera: Crambidae: Crambinae) in Florida. Pest Alert. FDACS 2p.

IBGE (2020) Instituto Brasileiro de Geografia e Estatística- Levantamento Sistemático da Produção Agrícola- Diretoria de Pesquisas – COAGRO/GEAGRI-LSPA 21p.

Knolhoff LM, Heckel DG (2013) Behavioral assays for studies of host plant choice and adaptation in herbivorous insects. Annu. Rev. Entomol. 59:263-278. https://doi.org/10.1146/annurev-ento-011613-161945

Lahiri S, Ni X, Buntin GD, Punnuri S, Jacobson A, Reay-Jones FPF, Toews MD (2019). Combining host plant resistance and foliar insecticide application to manage *Melanaphis sacchari* (Hemiptera: Aphididae) in grain sorghum. Int. j. pest manag. 67: 10-19. 10.1080/09670874.2019.1660830

Lara FM (1991) Princípios de Resistência de plantas a insetos. São Paulo: Ícone, 336 p.

Lara FM, Foss MRDA, Boiça Junior AL, Trigo JG (1997) Resistência de genótipos de sorgo a *Contarinia sorghicola* (Coq.) (Diptera: Cecidomyiidae) e *Diatraea saccharalis* (Fabr.) (Lepidoptera: Pyralidae) e influência sobre parasitoides. An. Soc. Entomol. Bras. 26: 327-333 https://doi.org/10.1590/S0301-80591997000200015

Legaspi JC, Saldana RR, Roseff N (1997) Identifying and managing stalkborers on Texas sugarcane. Texas Agricultural Experiment Station Publication MP-1777, College Station.

Magalhães PC, Durães FOM, Rodrigues JAS (2003) Fisiologia da Planta de Sorgo- Comunicado Técnico 86 SSN 1679-0162, Embrapa Milho e Sorgo, Sete Lagoas- MG, p.4.

May A. et al. Manejo de pragas na cultura do sorgo. **Informe Agropecuário**, Belo Horizonte, v. 35, n. 278, p. 14-20, 2014.

Mendes SM, Viana PA, Cruz I, Waquil JM (2012) Controle de Pragas. In: May, Durães, FOM, Pereira Filho IA, Schaffert RE, Parrella, RA da C (Eds.), Sistema Embrapa de produção de sorgo para bioetanol: Sistema BRS1G—Tecnologia Qualidade Embrapa. Sete Lagoas: Embrapa Milho e Sorgo.

Mendes SM, Waquil JM, Rodrigues JAS, Sampaio MV, Viana PA (2014) Manejo de pragas na cultura do sorgo. Informe agropecuário 1:76-88.

Menezes CB De, Coelho AM, Silva AF Da, Silva DD Da, Mendes SM, Albuquerque CJB, Rodrigues JAS (2018) É possível aumentar a produtividade de sorgo granífero no Brasil? In: CONGRESSO NACIONAL DE MILHO E SORGO, 32. Lavras. Soluções integradas para os sistemas de produção de milho e sorgo no Brasil: livro de palestras. Sete Lagoas: Associação Brasileira de Milho e Sorgo. cap. 4, p. 106-139.

Miranda RA, Gontijo MM, Garcia JC (2015) Análise comparativa da lucratividade dos plantios de milho e sorgo na segunda safra em Rio Verde – GO. XIII Seminário Nacional de Milho Safrinha- Maringá, PR, 2015.

Queiroz VAV, Menezes CB, Barros FAR, Martino HSD (2015) O sorgo na alimentação humana. Embrapa, Brasília-DF.

Silva DD, COTA LV, Costa RV da, Parreira D. F (2014) Principais doenças do sorgo. Informe Agropecuário, Belo Horizonte, v. 35, n. 278, p. 102-111.

Silva TI, Santana LD, Camara FT, Pinto AA, Brito LLM, Mota AMD (2017) Produtividade de variedades de sorgo em diferentes arranjos populacionais em primeiro corte e rebrota. Revista Espacios 38: 16-27.

VIlela M, Mendes SM, Viana PA (2014) Manejo de pragas do sorgo. Jornal Eletrônico da Embrapa Milho e Sorgo, Grão em Grão, Ano 08 - Edição 57, 2014.

Serra GV, Trumper EV (2020) Incidencia de *Diatraea saccharalis* (Lepidoptera: Pyralidae) sobre el rendimiento del cultivo de maíz y cálculo de niveles de daño económico. Agriscientia 37: 63-73 DOI:10.31047/1668.298x.v37.n1.24402

Vilela M, Mendes SM, Viana PA (2014) Manejo de pragas do sorgo. Jornal Eletrônico da Embrapa Milho e Sorgo (Sete Lagoas-MG), Ano 08 - Edição 57.

Vilela M, Santos AJN, Simeone MLF, Parrella AC, Silva DD, Parreira DF, Okumura F, Schaffert, RE, Mendes SM (2017) Influence of *Diatraea saccharalis* (Lepidoptera: Crambidae) infestation on sweet sorghum productivity and juice quality. Afr. J. Agric. Res. 12: 2877-2885.

Waquil JM (2001) Resistance of commercial hybrids and lines of sorghum, *Sorghum bicolor* (L.) Moench., to *Diatraea saccharalis* (Fabr.) (Lepidoptera: Pyralidae). Neotrop. Entomol. 30: 661-668 https://doi.org/10.1590/S1519-566X2001000400022

Waquil JM, Viana PA, Cruz I (2003) Manejo de pragas na cultura do sorgo. Embrapa Milho e Sorgo, Circular Técninca, Sete Lagoas, v. 27, 25p

Wilson BE, VanWeelden MT, Beuzelinc JM, Reagan TE (2018) Susceptibility and yield response to sugarcane borer (Lepidoptera: Crambidae) infestation among sugarcanes and sorghums with potential for bioethanol production. Crop Prot. 113: 15-21 https://doi.org/10.1016/j.cropro.2018.07.005

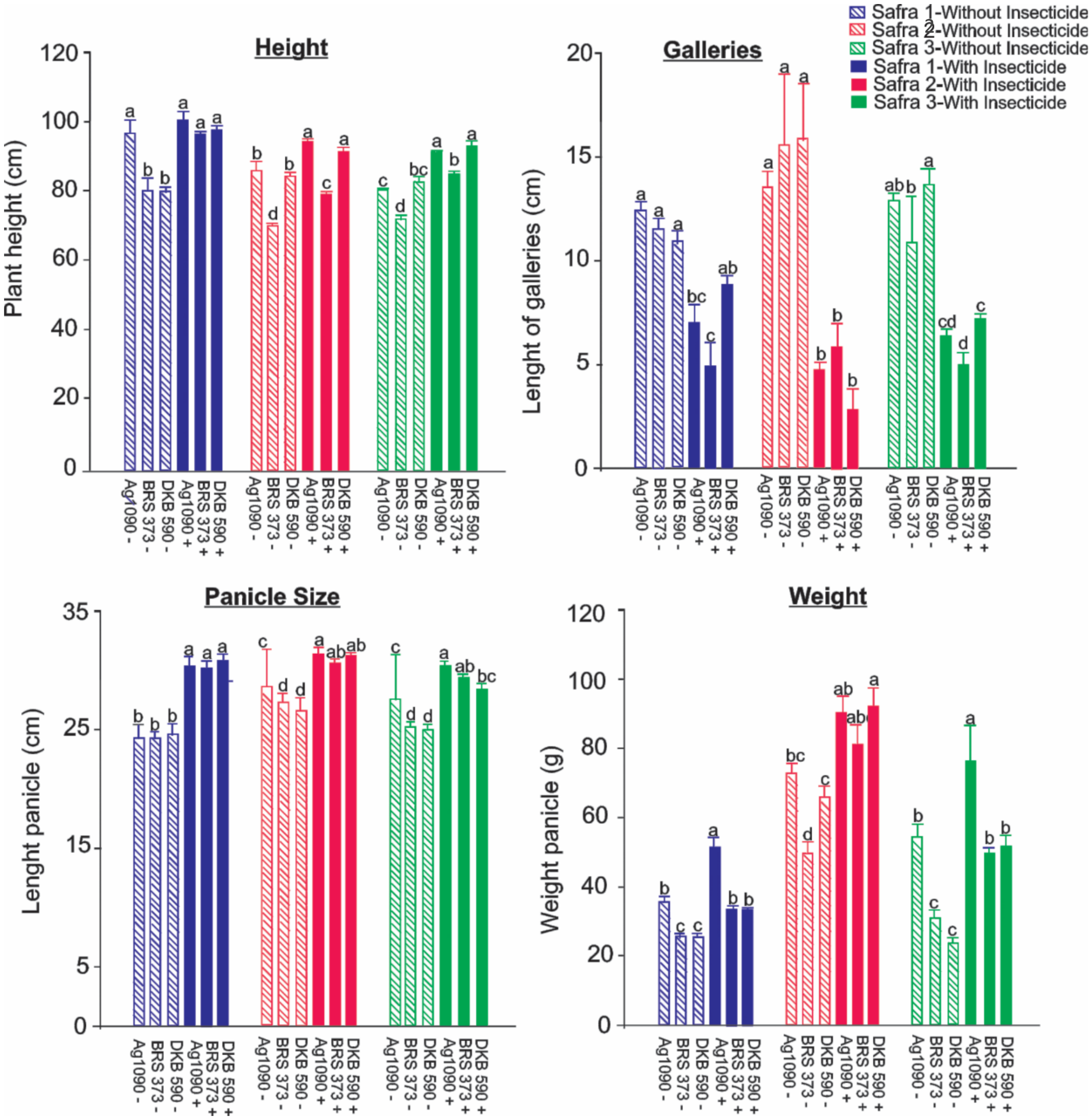

Figure 1- Variables plant height (cm), gallery length (cm), panicle weight and length of grain sorghum hybrids treated (with plus sign (+)) and not treated (with minus sign (-)) (crosshatched) with insecticide (chlorantraniliprole) under natural infestation of *Diatraea saccharalis* in three consecutive crop seasons ($P < 0.05$).

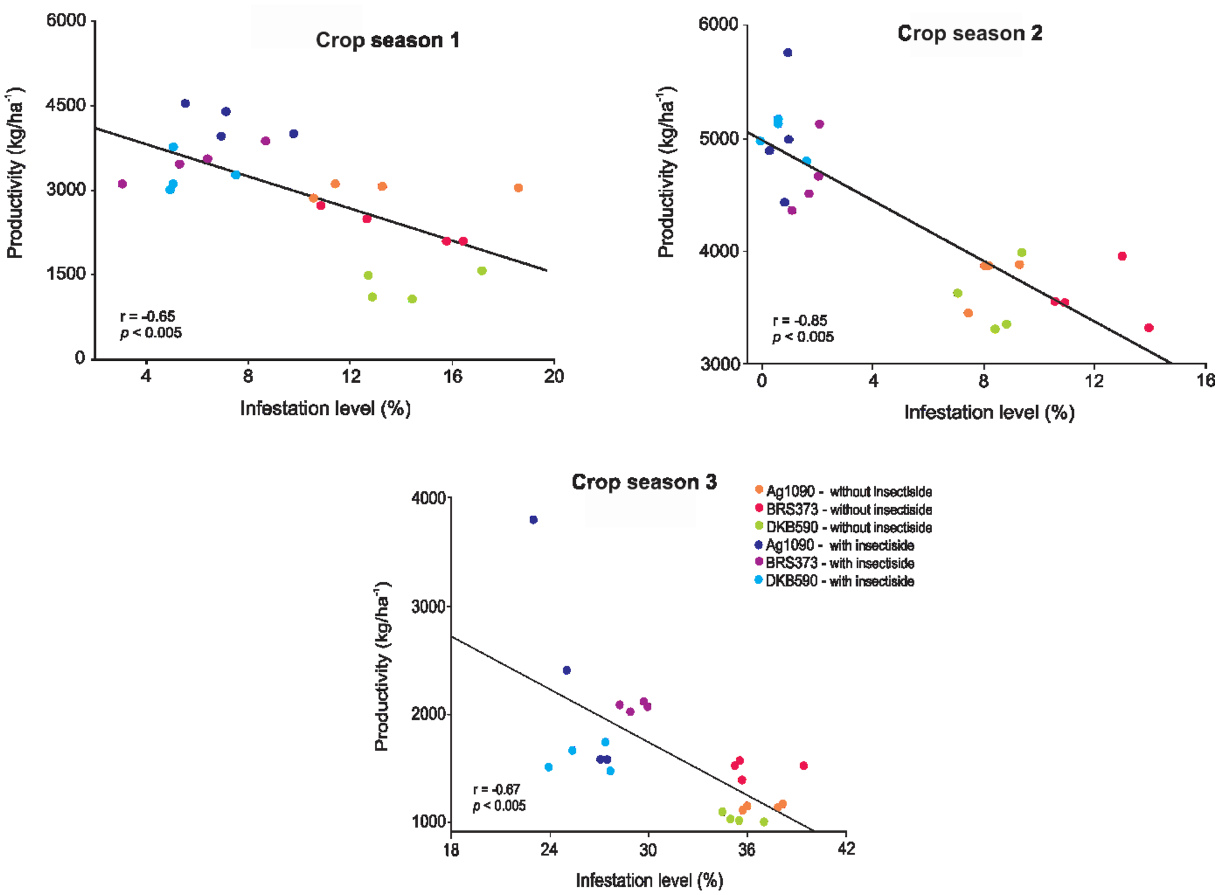

Figure 2. Pearson's correlation between Infestation intensity (%) and grain yield (kg ha-1) of grain sorghum hybrids treated and not treated with insecticide under natural infestation of *Diatraea saccharalis*.

ARTICLE 3- Susceptibility of grain sorghum hybrids to major agricultural pests

Camila S. F. Souza[1], Bruno H. S. Souza[1], Cícero B. Menezes[2], Maria Lúcia F. Simeone[2], Priscilla T. Nascimento[1], Josélia C. O França[1], Simone M. Mendes[2]*

[1]Department of Entomology, Universidade Federal de Lavras (UFLA), Campus Universitário, P.O. Box 3037, Lavras, MG, 37200-900, Brazil.

[2]Embrapa Milho e Sorgo (CNPMS), Rodovia MG 424, Km 45, P.O. Box 285, Sete Lagoas, MG, 35701-970, Brazil.

*Corresponding author: Simone Martins Mendes, simone.mendes@embrapa.br

Preparado segundo a norma e submetido à "ARTHROPOD-PLANT INTERACTIONS"

Declarations: This manuscript is original, unpublished and has not been submitted to another journal.

Orcid number:

Souza CSF: https://orcid.org/0000-0002-2740-9223

Souza BHS: https://orcid.org/0000-0002-2802-2688

Menezes CB : https://orcid.org/0000-0001-9437-6946

Simeone MLF: https://orcid.org/0000-0002-2003-0341

Nascimento PT: https://orcid.org/0000-0003-4366-4918

França, JCO: https://orcid.org/0000-0002-8515-2120

Mendes SM: https://orcid.org/0000-0002-9773-9017

Acknowledgments

The authors thank the Graduate Program in Entomology of the Federal University of Lavras for the scientific support to the students; Minas Gerais State Research Support Foundation (FAPEMIG) for granting a PhD scholarship to the first author; and Embrapa Milho e Sorgo for allowing this research to be carried out.

Ethics declarations

Conflict of interest

The authors declare no conflicts of interest regarding to the publication of this paper.

Ethics approval

Studies exempt from evaluation by the Research Ethics Committee

Abstract

Plant resistance is an important tactic within the precepts of Integrated Pest Management, and the existence of grain sorghum hybrids with multiple insect resistance could benefit the crop management and sustainability. The present study evaluated susceptibility of 30 grain sorghum hybrids to three major pests, *Spodoptera frugiperda*, *Diatraea saccharalis* and *Diceraeus melacanthus*. Cultivation of the hybrids and performance of experiments with each insect species were conducted separately in a greenhouse. For fall armyworm (FAW), larvae infestation took place with sorghum at the stage from four and six developed leaves and visual injury evaluation on plants were performed 7 and 14 days after infestation (DAI). For sugarcane borer (SCB), plants were infested at the same growth stage and assessed 40 DAI for the insect presence and injury. For the green-belly stink bug (GBS), the infestation was performed three days after emergence, and plants were evaluated using a damage score scale 12, 19 and 26 days after infestation. Through cluster analysis, it was possible to separate the grain sorghum hybrids into groups regarding the resistance levels to each pest. The hybrid BRS373 stood out as moderately resistant to FAW; AG1090, 80G20, BRAVO, BRS373, AG1615, and IG220 were the most promising for SCB; and for GBS, the hybrids 50A40, A9735R, JADE, ENFORCER, BUSTER, 50A10 and IG244 were the most nominated. Further research should evaluate the potential chemical and morphological plant traits underlying the lower susceptibility levels found in the selected sorghum hybrids to FAW, SCB, and GBS. This information will greatly aid sorghum breeding programs focused in developing commercial hybrids possessing both insect-resistance and high-yield characteristics.

Keywords: Host plant resistance, *Sorghum bicolor*, *Spodoptera frugiperda*, *Diatraea saccharalis*, *Dicereaus melacanthus*.

Declarations: The abstract covers the main methodology and the main results

Introduction

Sorghum, *Sorghum bicolor* (L.) Moench, is an important cereal crop used for grain, feed, and energy production. It is the fifth most produced cereal in the world, and can substitute corn in animal feed. Sorghum grains also constitute a staple food for people in some countries in Africa and Asia, and hold promise for human consumption elsewhere since they are rich in bioactive and functional compounds, and are gluten-free (Waquil et al. 2003; FAO 1995; Martino et al. 2014).

The demand for sorghum-based products, such as bread, pasta, cereal bars, snacks, cakes, biscuits, and beer has grown in recent years; all these products show high added value due to the benefits for human nutrition and health as an alternative to conventional cereals (Martino et al. 2014; Abdelghafor et al. 2011; Burdete et al. 2010; Cardoso et al. 2014). Brazil is currently the ninth largest sorghum producer globally, being responsible for ~10% total grain sorghum production. In the 2019 crop season in Brazil, nearly 2.5 million tons of sorghum grains were produced, with the state of Goiás standing out among the Brazilian producing regions, with more than 40% of the national production, followed by Minas Gerais state (IBGE 2020). However, losses by infestation of insect pests constitute one of the major problems in sorghum production. Insect pest attacks can occur in all phenological stages of sorghum, which affect development and productivity of the plants. Fall armyworm *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) has often been reported as one of the main pests of grain sorghum. FAW is one of the most harmful insect pests of annual crops in tropical regions of the Americas, being able to cause production losses between 17 and 39% depending on the environment and developmental stage of the attacked plants. In Brazil, FAW is also an important pest of maize, cotton, soybean, and sugarcane, among other crops of economic importance (Cruz and Turpin 1982; Boregas et al. 2013; Bernardi, et al. 2015, Goergen et al. 2016). Thus, FAW infestations in these crop plants in adjacent areas or in succession can affect damage intensity to sorghum.

Another important lepidopteran pest is sugarcane borer (SCB) *Diatraea saccharalis* (Fabricius) (Lepidoptera: Crambidae). SCB is responsible for making galleries in the plants stems, weakening these structures and hampering photoassimilates translocation. In addition, indirect losses are caused by the entry of microorganisms via injured areas caused by SCB to the stem, which can lead to reduced grain production. SCB is a pest of agricultural systems not only in Brazil, but also in the USA in rice, sugarcane, and sorghum (Hayden 2012; Legaspi et al. 1997). In some regions of Brazil, the damage caused by SCB can correspond to 30% of total sorghum grains production (Mendes et al. 2012, 2014).

Due to cultivation of maize and sorghum in the second crop season in succession with soybeans, insect pests that were previously considered as secondary have increased in frequency of occurrence in crops grown in no-tillage systems in Brazil, as is the case with green-belly stinkbug (GBS) *Diceraeus melacanthus* (Dallas) (Hemiptera: Pentatomidae). GBS has a habit of feeding and reproducing under the straw left by preceding crops, causing significant damage to maize and sorghum plants at the beginning of vegetative development, reducing the vigor and possibly causing death of infested plants (Conab 2020; Gassen 1996; Corrêa-Ferrera; Sosa-Goméz 2017). When feeding, GBS normally positions itself at the base of stem of host plants with the head positioned downward, where the stinkbug introduces the stylets to suck the phloem sap. Sap sucking is facilitated by injection of salivary enzymes that are toxic to the plant, hindering its development (Bianco 2004; Grigolli et al. 2016).

In terms of genetic variability of plants in relation to insects attack, different genotypes can present higher or lower levels of resistance/susceptibility (Bastos et al. 2015). Given the fact that host plant resistance to insects is horizontal in the majority of cases, i.e. the resistance is controlled by various quantitative genes and loci, plants generally present varying response levels to pest injury, as well as in terms of effects on insect feeding, oviposition, and development. Additionally, plant resistance can be specific for a species or group of insects, while the plant remains susceptible to other pests depending on the history of insect adaptation. At the same time, multiple resistance occurs when a plant genotype presents resistance-related traits to various insect species (Kogan 1975; Lara 1991; Baldin et al. 2019), which is a desired characteristic of commercial cultivars to be used in Integrated Pest Management (IPM) systems. Ultimately, host plant resistance is a control tactic that can be applied in combination with most control tatics within the IPM precepts to minimize problems caused by excessive use of chemical insecticides.

Most studies that evaluated grain sorghum genotypes for resistance to SCB and other lepidopterans in Brazil were conducted over 20 years ago, especially during the 1980s and 1990s. In these studies, sources of resistance to SCB and FAW were found to some extent through evaluation in plant parameters such as damage scores relative to larvae infestation, pest infestation intensity, and insect biology (Waquil et al. 1980; Boiça Jr. and Lara 1983; Lara et al. 1997; Waquil and Santos 1990; Waquil et al. 2001). Because these evaluations were performed long time ago, novel resistance screening phenotyping should be conducted with more recent and improved genotypes seeking the introgression of the resistant genes into germplasm of grain sorghum breeding programs. Additionally, there is no information on the responses of sorghum genotypes in terms of resistance to insect pests such as GBS that have gained recent economic importance in agricultural systems.

Studying the behavioral and developmental parameters of insect pests and evaluating the injury intensity on host plants is essential to assist screening of hybrids resistant to the main grain sorghum pests and to achieve higher efficiency in the management and profitability of producers (Knolhoff and Heckel 2013). It also benefits genetic breeding programs by the production of hybrids with desirable agricultural traits and at the same time moderate-to-high resistance levels to major crop insect pests. Information available so far in the literature for potential multiple- resistance of grain sorghum genotypes to SCB, FAW, and GBS is scarce given that infestations of these pests in sorghum crops are relatively recent in the main producing regions in Brazil. Thus, this study was conducted to evaluate the susceptibility of 30 grain sorghum hybrids to three important pests of grain sorghum, fall armyworm (FAW), sugarcane borer (SCB), and green-belly stinkbug (GBS).

Declarations: The introduction covers the main information on the topic

Materials and Methods

Experimental conditions and grain sorghum hybrids

The study was carried out in a greenhouse of Embrapa milho e Sorgo, in Sete Lagoas, MG state, Brazil, under the conditions of 25 ± 5°C, 70 ± 15% UR, and natural photoperiod. Thirty grain sorghum hybrids already available in the marketplace were evaluated for resistance to the three insect species (FAW, SBC, GBS), as follows: BRS373, FOX, DKB590, 1G220, AG1090, BRAVO, MSK327, 1G244, 50A10, 50A40, 50A70, 70G70, XGN1305, 80G20, MSK326, XB6022, AG1080, A9735R, AG304, 1G100, A9902, A9721R, AS1615, BUSTER, DKB550, MSK321, JADE, 1G232, ENFORCER, and MSK120.

Assays was conducted in three 20-L pots used for each evaluated hybrid, with soil fertilized with 50 g of NPK 08-28-16 and 0.3% of Zn/100 kg.v. Each pot was considered a replication, totaling 90 pots used in each experiment with different insect species. Thinning of plants was performed 10 days after sowing, keeping three plants per pot. The assays with the three insect pests were carried out separately, in a completely randomized design.

Rearing of insect species

Fall armyworm (FAW): Testing insects of FAW were obtained from a rearing colony in laboratory. Briefly, larvae were reared on artificial diet based on cooked beans, wheat germ, and casein (Cruz 2000). Adults were transferred to cylindrical PVC mating cages (40 cm h x 30 cm diam.) containing moth food (10% sugar and 5% ascorbic acid in water) and white sulfite paper on the inner walls for oviposition. Collected egg masses were left to hatch in plastic bags, and neonates were transferred to the artificial diet (Cruz 2000). Newly hatched larvae obtained from the laboratory rearing colony were individually placed in 50-ml plastic cups sealed with acrylic lids (adapted from Mendes et al. 2011).

Sugarcane borer (SCB): Adults of SCB were kept in PVC cages covered with sulfite paper for oviposition. The cages were covered with voile fabric on the top that was fixed with rubber bands. Collected eggs were washed in a deionized water and 1% sodium hypochlorite solution, and then deionized water and a solution of deionized water with 1% copper sulphate to avoid microorganism contamination. Eggs were dried at room temperature, and subsequently placed in glass jars (8.5 cm x 2.5 cm) covered with voile fabric containing artificial diet based on soybean meal, sugar, and wheat germ (adapted from Hensley and Hammond 1968), where they remained until the third instar (approximately 20 days-old). Larvae were transferred to Petri dishes (5 cm diameter) with artificial diet cut into strips, due to natural larvae behavior in forming galleries. The larvae remained in Petri dishes until adult emergence. (vilela, et al 2017)

Green-belly stinkbug (GBS): Insects of GBS were reared in plastic cages (37 x 12 cm) with perforated lids to allow for air exchange, pieces of voile fabric for oviposition, water-soaked cotton wool to provide water, and a mixture of seeds of beans, sunflower, soybeans, and peanuts as food sources. The younger nymphal phases were maintained separate from the adults.

Rearing of the three insect species was carried out in a climatized chamber under controlled environmental conditions (25 ± 2°C, 60 ± 10% U.R., and 12C:12E h).

Fall armyworm assay

For the assay with FAW, infestation with larvae was carried out when sorghum plants were at the growth stage of four completely developed leaves. Five neonate larvae (<24 hours-old) were transferred per plant using a fine paintbrush where three plants/pot were placed, totaling 15 larvae per pot. The pots were covered with voile fabric cages to prevent insects escaping from the plants.

Evaluations of injury caused by FAW feeding on the plants were carried out using an damage score scale ranging from 0-9, according to that proposed by Davis in maize and adapted to sorghum (Davis and Williams 1992),: 0 = no visible injury; 1 = punctures (more than one point per plant); 2 = scrapes and 1 to 3 small circular lesions (<1.5 cm); 3 = 1 to 5 small circular lesions (<1.5 cm) and 1 to 3 elongated lesions (<1.5 cm); 4 = 1 to 5 small circular lesions <1.5 cm) and 1 to 3 elongated lesions (>1.5 cm and <3 cm); 5 = 1 to 3 large elongated lesions (>3 cm) in 1 to 2 leaves and 1 to 5 perforations or elongated lesions (<1.5 cm); 6 = 1 to 3 large elongated lesions (>3 cm) in 2 or more leaves and 1 to 3 large perforations (> 1.5 cm) on 2 or more leaves; 7 = 3 to 5 large elongated lesions (>3.5 cm) in 2 or more leaves and 1 to 3 large perforations (>1.5 cm) on 2 or more leaves; 8 = many elongated lesions (>5cm) of all sizes on the majority of the leaves; many medium to large perforations (> 5) >3 cm on many leaves; 9 = many leaves affected, nearly all destroyed. Damage scores were determined at 7, 14 and 21 days after FAW larvae infestation (DAI).

Sugarcane borer assay

When sorghum plants presented between four and six developed leaves (Magalhães et al. 2003), they were manually infested with five SCB neonate larvae per plant using a fine paintbrush. The neonate larvae (<24 hours-old) were obtained from the rearing colony.

Evaluation of injury by SCB was performed 40 DAI on the sorghum plants. To this end, the plants were cut close to the ground and opened longitudinally with a razor blade to detect the presence and quantify injury by SCB. Evaluated parameters were the number of healthy and bored internodes, length (cm) of the galleries made by SCB, and infestation intensity (%). The infestation intensity (I.I.) was calculated with the following formula: I.I. (%) = number of bored internodes/total number of internodes x 100 (Gallo et al. 2002).

Green-belly stinkbug assay

For the assay with GBS, one adult stinkbug was manually infested per plant, using one plant per pot. The adults were obtained from the rearing colony and were fasted for 16 hours prior to infestation in order to stimulate feeding soon after being released onto the plant. Infestation was performed three days after seedlings emergence, and adult GBS was kept feeding on the plant for 12 days, according to the method of Gomes et al. (2011). During this period, all the pots were protected with PET perforated bottles to allow air circulation and avoid insects from escaping. Evaluations on infested plants were performed every two days to observe insect survival and replenish dead stinkbugs. The first evaluation was performed 12 DAI, soon after insects removal from plants.

Evaluation of GBS injury was based on the damage score scale adopted by Roza-Gomes et al. (2011), as follows: score 0 = plants presenting no injury; 1 = leaves with punctures without reduction in plant size; 2 = slight injuries on the plant, partially rolled, with reduction in size; 3 = trapped or plant tiller; 4 = dry or dead plant (Figure 3). Nineteen days after infestation, i.e. seven days after the first evaluation, the second evaluation was performed with the characterization of damage score and developmental stage of plants, according to Roza-Gomes et al. (2011). Finally, 27 DAI, i.e. 14 days after the first evaluation, a third and final injury evaluation on the plants was performed.

Statistical analysis

For univariate analysis the data obtained in each bioassay, for each species of insect were subjected the Shapiro-Wilk test was performed to check normality and the Bartlett test was used to check for homogeneity of variances. As data did not follow a normal distribution or exhibited heterogeneity of variances, a nonparametric test was performed using generalized linear model (GLM) and quasipoisson family, and the means of treatments were compared by Tukey's (α=0.05). The analyses were performed using the statistical R software version 3.5.3 (R Development Core Team 2014).

For multivariate analysis, it was used the hierarchical clustering Unweighted Pair-Group Method using Arithmetic Avarages (UPGMA) method was used in cluster dendrograms fixed with three groups and using the Euclidean distance as dissimilarity unit measure. The analyses were performed using the statistical R software version 3.5.3 (R Development Core Team 2014).

Declarations: The Materials and Methods explains all the methodology used and how the statistical analyzes were performed

Results

Fall armyworm assay

The first FAW injury evaluation on sorghum plants was carried out 7 days after infestation (DAI), where the hybrid BRS373 showed a mean injury score lower than that in the other hybrids, followed by MSK327 (F= 2.10, df= 29, P< 0.005). These two hybrids maintained the lower injury scores at 14 DAI, together with hybrid A9735R (F= 1.94, df= 29, P< 0.005). The hybrid BRS373 and A9735R maintained the lower injury scores at 21 DAI (F= 2.22, df= 29, P< 0.005). Most of the hybrids presented lower damage scores at 7 DAI in comparison with 14 and 21 DAI (table 1).

By using the cluster dendrogram, it was possible to separate the grain sorghum hybrids into three groups according to their similarity regarding the evaluated plant injury parameter. Hybrid BRS373 was considered moderately resistant; MSK327 and A9735R were classified as susceptible; while the other hybrids were highly susceptible to FAW (**Fig. 1**).

Sugarcane borer assay

In the assay with SCB, there were significant differences (P <0.05) for all parameters evaluated, except infestation intensity. In the assay with SCB, the hybrids BUSTER and 50A70 had higher numbers of bored internodes (F= 8.21, df= 29, P< 0.005) and consequently lower numbers of healthy internodes (F= 4.49, df= 29, P< 0.005). In addition, no bored internodes were observed in hybrids AG1090, 80G20, AS1615, BRS373, BRAVO, and IG220, consequently did not present any injury (0 % infestation intensity) (F= 2.12, df= 29, P< 0.005). Regarding the galleries caused SCB by feeding, hybrid 50A70 showed greater injury, followed by A6304, JADE, DKB590 and FOX ATLÂNTICA (F= 24.37, df= 29, P< 0.005). The hybrids AG1090, 80G20, BRAVO, BRS373, AS1615, and 1G220 did not present any galleries (Table 2).

By using the cluster dendrogram, it was possible to separate the grain sorghum hybrids into three groups according to their similarity. Based on the evaluated parameters, the hybrid 50A70 was classified as highly susceptible to SCB, while the hybrids A6304, JADE, MSK321, BUSTER, FOX-ATLÂNTICA, XGN1305, DKB550 and DKB590 were considered susceptible; the other hybrids were classified as moderately resistant to SCB, highlighting AG1090, 80G20, BRAVO, BRS373, AS1615, and 1G220 by presenting no injury signals in the plants (**Fig**. **2**).

Green-belly stinkbug assay

In the assay with GBS, GLM analysis showed no significant difference between treatments on different days of evaluations. However, we can highlight the hybrids 50A40 and A9735R presented the lowest injury scores with means of injury below one in the three evaluations at 12 DAI (F= 2.12, df= 29, P< 0.005), 19 DAI (F= 1.66, df= 29, P< 0.005) and 26 DAI (F= 1.87, df= 29, P< 0.005). On the other hand, the hybrids 80G20 and MSk326 showed the highest scores of injury by GBS in general (Table 3).

These results match the multivariate analysis it was possible to separate the grain sorghum hybrids into three groups by using the cluster dendrogram according to their similarity for the evaluated parameters. The hybrids JADE, ENFORCER, BUSTER, IG244, 50A10, 50A40, and A9735R were classified as moderately resistant, standing out the latter two hybrids that presented the lowest mean damage scores. The hybrids IG100, MSK327, AG1090, DKB550, AS1615, FOX-ATLÂNTICA, IG233, A9902, 50A70, A9721R, DKB590, and XB6022 were considered susceptible; and the other hybrids were classified as highly susceptible to GBS, among them 80G20 and MSk326 overall showed the highest damage scores of GBS injury (**Fig 3**).

Declarations: All results were presented explicitly in texts, figures and tables

Discussion

Information on the resistance levels expressed by different grain sorghum hybrids available on the market to major insect pests infesting the crop constitute an important tool to help in selecting hybrids with multiple desirable defense traits and for use in IPM systems, especially when considering which pest species is prevalent in the given conditions under which sorghum is grown. In the present study, genetic variability between the grain sorghum hybrids in terms of the resistance levels to FAW, SCB, and GBS was investigated in greenhouse conditions. This variation in hybrid susceptibility to insect pests is important to give farmers greater support when choosing the hybrid more suitable for use in specific IPM cropping systems.

In the FAW assay, evaluation of hybrids allowed the identification of BRS373, MSK327, and A9735R as presenting the lowest injury by FAW after the evaluation period. This methodology of injury evaluation was also used and allowed for the differentiation of maize and sorghum genotypes using the damage score scale for FAW, and complemented with biological evaluation of pest development. All these studies found great variation in the responses between genotypes, some of which were selected as potential resistant, whether the evaluations were carried out in the field, greenhouse or laboratory (Cortéz and Waquil 1997; Gonçalves et al. 2011; Burtet et al. 2017; Crubelati-Mulati et al. 2019).

Our results indicates presence of resistance genes to FAW in the highlighted hybrids BRS373, MSK327, and A9735R, given that achieving differences between genotypes for FAW injury is not common, especially due to the larvae voracity and high polyphagy characteristics, making them able to feed on various crop plants with high degree of adaptation (Boregas 2013). Therefore, the lower damage scores found herein could be considered by sorghum producers as a reliable proxy for hybrid choice in terms of the potential for possessing some resistance level to FAW attack.

Furthermore, some hybrids, although classified as highly susceptible to FAW, such as 50A40, 50A70, A9902, AS1615, MSk321, MSk326, MSK327, XGN1305, and MSK320, did not progress in the increase of injury between the two evaluations. This may be due to the resistance and/or tolerance levels of these plants. As in this study, insect parameters such as larval weight and mortality were not evaluated, but only injury to sorghum plants; minor injury may have occurred due to negative effects on insect feeding and growth (antixenosis and antibiosis resistance), as well as due to better plants ability to support and regenerate damaged tissues (tolerance). However, it is not possible to assert these questions based on our assessments, and these evaluations are suggested to be carried out in the future to characterize the presence of resistance and/or tolerance in these hybrids.

In the SCB assay, the hybrids BRS373, BRAVO, AS1615, AG1090, 80G20, and IG220 highlighted without SCB-made galleries, and the hybrids MSK320, A9735R, IG233, and MSK327 as presenting both smallest-sized galleries and lowest infestation intensity. Evaluations of galleries and infestation intensity are considered the most adequate parameters for identification of resistance sources to SCB in sorghum (Waquil et al. 2001). Among those hybrids, BRAVO was also identified as one of the least susceptible to losses caused by *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae) in stored grains; this information is very important given that this hybrid was also found to be less susceptible to main pests throughout the whole crop cycle until the end of the production chain, i.e. from the field up to storage (Pimentel et al. 2018).

Infestation intensity is a more accurate plant parameter for predicting production losses, and this variable is also used in sugarcane and other types of sorghum as proxy of resistance levels to SCB attack (Milligan et al. 2003; Araújo et al. 2019; Vilela et al. 2017). According to Gallo et al. (2002), the values shown in the parameters of infestation intensity and infestation percentage allow injury to be classified as low, with values of 0-5% and 0-25%; moderate, from 5-10% and 25-50%; regular, from 10-15% and 50-75%; elevated, from 15-25% and 75-95%; and extremely elevated, above 25% and 95%, respectively. For sugarcane, the economic threshold is fixed at 3% infestation intensity, in that an infestation intensity of 1% can lead to reductions of up to 0.28% in alcohol production, 0.49% in sugar production, and 1.5% in stems production (Arrigoni 2002). For sorghum plants, which are more tolerant to SCB attack in comparison to sugarcane, an economic threshold of 4% for infestation intensity can be used for the decision-making of pest control (Vilela et al. 2014).

Studies evaluating different grain sorghum hybrids for the resistance to SCB have been performed some time ago, including the evaluation of effects of fertilization, pest biology, and plant growth parameters (Lara et al. 1991; Lara et al. 1997; Cortez and Waquil 1997; López et al. 2000; Waquil et al. 2001; Bortoli et al. 2005). Results of these studies found correlations with ample genetic variability between sorghum genotypes, some of them being resistant to SCB. Of the genotypes that stood out for SCB resistance, the hybrid AF-28 is known for possessing multiple insect resistance; in addition to SCB, the hybrid presents resistance to sorghum midge *Stenodiplosis* (=*Contarinia*) *sorghicola* (Coquillet) (Diptera: Cecidomyiidae) and corn aphid *Rhopalosiphum maidis* (Fitch) (Hemiptera: Aphididae). However, hybrid AF-28 presents undesirable agronomic characteristics, such as late development and non-erect formation (Rosseto et al 1976; Boiça Junior and Lara 1983; Rosseto and Igue 1983; Lara and Perussi 1984; Lara et al. 1997). Therefore, evaluations of different genetic materials should not only take into account the resistance to the pest in question, but should also consider other plant parameters, which can result in the identification of genotypes with all desired characteristics for a cost-effective grain production.

Occurrence of GBS in maize and sorghum cropping systems has been frequent in recent years due to the intensification of second crop cultivation soon after harvesting of soybean crop (Corrêa-Ferreira and Sosa-Gómez 2017). This is the first study conducted for the recommendation of grain sorghum hybrids with resistance to GBS. Here, plants of sorghum hybrids were infested with one adult stinkbug, and hybrids 80G20 and MSK326 at the evaluations of 19 and 26 DAI did not present signs of recovery, and hence were the hybrids more susceptible to

GBS. The hybrids 50A40 and A9735R stood out as the most resistant to GBS, which presented the lowest damage scores over the three evaluation dates.

Studies carried out with maize genotypes using the injury scale for GBS are more common in the literature than for sorghum. Roza-Gomes et al. (2011) observed a mean damage score of 2.8 using the density of five stinkbugs infested on five maize plants, starting from V1 stage. In the present study, the use of the damage score scale modified from maize evaluation was an efficient method to detect differences in susceptibility to GBS among the sorghum hybrids (Roza-Gomes et al. 2011; Bridi. et al. 2016; Cruz et al. 2016; Duarte et al. 2015). Therefore, its use can be recommended in future studies with evaluation of resistance in grain sorghum to GBS.

Given that GBS is usually already present in the field at beginning of maize and sorghum plants development, it is very important that the plants are able to recover from stinkbug injury along the development, otherwise they may die or show increased tillering, which is undesirable for grain sorghum production. Following stem and plant development, susceptibility to the pest is significantly reduced; however, when injury intensity is high, the chance of plant recovering over time is lower. Therefore, the hybrids responses to GBS infestation should be evaluated early on in the first stages of plant development, as was done in this study, since it is the most susceptible growth stage that the insect is able to inflict damage (Sturza et al. 2020). In this manner, in studies involving the selection of resistant grain sorghum hybrids to GBS, evaluations during these phenological stages can provide more precise and reliable results in terms of the presence of resistance and tolerance traits.

The 30 grain sorghum hybrids evaluated herein showed quite different responses in relation to three major insect pests of the crop. This was expected since generally host plant resistance is specific for a determined pest species and the same genotype can be susceptible to other species. The same genotype may present moderate resistance for another pest while also showing different results depending on environmental conditions due to the genes x environment interactions. Additionally, other parameters can affect the responses of hybrids such as phenological asynchrony, plant age, prior infestation by other pests or diseases, atmospheric conditions, soil fertility, amongst others (Rossetto et al. 1976; Baldin and Bentivenha 2019).

In agricultural systems where FAW historically occurs in large populations, there is a need for more frequent monitoring to support the decision making of pest control, such as chemical and biological insecticides application at adequate times when the economic threshold is reached, although this information for FAW in sorghum is still lacking. Furthermore, given that the market value of sorghum grains has been high in the last years (Conab 2018, 2020), farmers have been concerned about plant health conditions, investing more time and resources in pest control measures (Rosseto et al. 1976; Boiça Junior and Lara 1983; Rosseto and Igue 1983; Lara and Perussi 1984; Cortéz and Waquil 1997; Lara et al. 1997; Carvalho and Dias 2020).

Despite the satisfactory results obtained here, where it was possible to indicate a less susceptible sorghum hybrid for each insect pest, in light of new techniques and perspectives for research on host plant resistance, together with the increased crop importance in terms of planted area and economic profitability for the sorghum farmers, more research is necessary with the aim of increasing productivity and resistance levels to the major insect pests. This is important since sorghum is a plant species that hosts the three pests throughout their phenological development. GBS is a problem at the beginning of crop development, and is considered a limiting biotic stressor on plant growth in sensitive stages, such that the greater the injury on the plants, the lower the chances of recovery (Figure 4). FAW in turn can cause total leaf loss of in the attacked plant, as was observed in this study in hybrids with high damage scores (8-9), totally undermining plants photosynthesis. SCB that feed on the stem, makes galleries that weaken the plants, rotting by favoring the entry of microorganisms leading to mycotoxins accumulation, death of the apical meristem, reduction of sap flow, and general plant debilitation (Mendes et al. 2014; Silva et al. 2014) (Figure 4).

As the main conclusions of this study in terms of the lower levels of susceptibility to attack by the three major insect pests, for improved management of FAW the hybrids BRS373, MSK327, and A9735R are recommended; for SCB, the highlighted hybrids are AG1090, 80G20, BRAVO, BRS373, AG1615, and IG220; and for GBS, the hybrids 50A40, A9735R, JADE, ENFORCER, BUSTER, 50A10, and IG244 are the most promising. Further research should evaluate the potential chemical and morphological plant traits underlying the lower susceptibility levels found in the selected sorghum hybrids to FAW, SCB, and GBS. This information will greatly aid sorghum breeding programs focused in developing commercial hybrids possessing both insect-resistance and high-yield characteristics.

Declarations: All results were discussed and based on the literature and original explanatory figures were added. All authors contributed to the realization of this manuscript.

References

Abdelghafor R, Mustafa A, Ibrahim A, Krishnan PG (2011) Quality of bread from composite flour of sorghum and hard white winter wheat. Adv J Food Sci Technol 3: 9-15.

Araújo OG, Vilela M, Simeon, ML, Silveira LCP, Fadini MAM, Parrella RAC, Mendes SM (2019) Resistance of bioenergy sorghum to *Diatraea saccharalis* (Lepidoptera: Crambidae). Biosci. J 35: 1022-1032. https://doi.org/10.14393/BJ-v35n4a2019-41770

Arrigoni EB (2002) Broca da cana: importância econômica e situação atual. In Pragas da cana-de-açúcar: importância econômica e enfoques atuais. Edited by Arrigoni E.B., Dinardo-Miranda L.L., Rossetto R. STAB/IAC/CTC Piracicaba, São Paulo, Brazil. pp. 1-4.

Baldin ELL, Bentivenha JPF (2019) Fatores que afetam a expressão da resistência. In: Baldin, ELL, Vendramim JD, Lourenção A L (eds) Resistência de plantas a insetos- Fundamentos e Aplicações. Piracicaba, São Paulo, Brasil: Fealq. p. 323-356.

Bastos CS, Ribeiro AV, Suinaga FA, Brito SM, Oliveira AAS, Barbosa TM, Santos P de J. dos, Oliveira DVV, Telchmann YSK (2015) Resistência de plantas a insetos: contextualização e inserção no MIP. In: Visotto LE, Fernandes FL, carvalho Filho A, Lopes EA, Aquino LA de, Fernandes ME de S, God PIVG, Ruas RAA, Sousa Júnior J M de (Ed.) Avanços tecnológicos aplicados à pesquisa na produção vegetal. Editora Suprema, Embrapa Hortaliças, Brasília, p. 31-72.

Bernardi O, Bernardi D, Ribeiro RS, Okuma DM, Salmeron E, Fatoretto J, Medeiros F CL, Burd T, Omoto C (2015) Frequency of resistance to Vip3Aa20 toxin from *Bacillus thuringiensis* in *Spodoptera frugiperd*a (Lepidoptera: Noctuidae) populations in Brazil. Crop prot 76: 7-14. https://doi.org/10.1016/j.cropro.2015.06.006

Bianco R (2004) Nível de dano e período crítico do milho ao ataque do percevejo barriga verde (*Dichelops melacanthus*). In: Congresso nacional de milho e sorgo, 25.; Simpósio brasileiro sobre a lagarta-do-cartucho, *Spodoptera frugiperda*, 1. Cuiabá. Resumos. Sete Lagoas: ABMS: Embrapa Milho e Sorgo: Empaer, 2004. p. 172.

Boiça Júnior AL, Lara FM (1983) Avaliação da resistência de genótipos de *Sorghum bicolor* (L.) Moench a *Diatraea saccharalis* (Fabricius, 1794) (Lepidoptera-Pyralidae) e determinação dos tipos envolvidos. An. Soc. Entomol. Bras 12: 261-272.

Boregas KGB, Mendes SM, Waquil JM, Fernandes GW (2013) Estádio de adaptação de *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) em hospedeiros alternativos. Bragantia 72: 61-70. https://doi.org/10.1590/S0006-87052013000100009

Bortoli AS, Dória, HOS, Albergaria, NMMS (2005) Biological aspects and damage of *Diatraea saccharalis* (Lepidoptera: Pyralidae) in sorghum, under different doses of nitrogen and potassium. Ciênc. Agrotec. 29: 267-273. https://doi.org/10.1590/S1413-70542005000200001

Bridi M, Kawakami J, Hirose E (2016) Danos do percevejo *Dichelops melacanthus* (Dallas, 1851) (Heteroptera: Pentatomidae) na cultura do milho. Magistra 28: 301-307.

Bueno A de F, Corrêa-Ferreira BS, Roggia S, Bianco R (2015) Silenciosos e daninhos. Revista Cultivar: Grandes Culturas 6: 25-27.

Burdette A, Garner PL, Mayer EP, Hargrove JL, Hartle DK, Greenspan P (2010) Anti-inflammatory activity of select sorghum (*Sorghum bicolor*) brands. J. Med. Food 13: 1-9. 10.1089/jmf.2009.0147

Burtet LM, Bernardi O, Melo AA, Pes MP, Strah TT, Guedes JVC (2017) Managing fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), with Bt maize and insecticides in southern Brazil. Pest Manag Sci 73: 2569-2577. 10.1002/ps.4660

Cardoso LMPSS, Martino HSD, Pinheiro SHM (2014) Sorghum (*Sorghum bicolor* L.): nutrients, bioactive compounds and potential impact on the human health. Crit. Rev. Food Sci. Nutr 57: 372-390. 10.1080/10408398.2014.887057

Carvalho R, Dias RC (2020) Milho ou Sorgo na Safrinha, Qual a melhor decisão? Informativo Agroservice KWS, 2p.

Conab (2021) Companhia Nacional de Abastecimento. Parâmetros de análise de mercado do sorgo - médias mensais. Brasília: Conab, 5p.

Conab (2020) Companhia Nacional de Abastecimento. Nono levantamento da safra brasileira de grãos (safra 2019/2020). Brasília: Conab, v. 7, 31p.

Chupin L, Rider D de, Clément-Vidal, A, Soutiras A, Gineau E, Mouille G, Arnout S, Brancourt-Hulmel M, Lapierre C, Pot, D, Vincent L, Mija A, Navard P (2017) Influence of the radial stem composition on the thermal behaviour of miscanthus and sorghum genotypes. Carbohydr. Polym 167: 12-19. https://doi.org/10.1016/j.carbpol.2017.03.002

Corrêa-Ferreira BS, Sosa-Goméz DR (2017) Percevejos e o sistema de produção soja-milho. Documentos 397 ISSN 2176-2937- Embrapa Soja, Londrina PR.

Cortez MGR, Waquil JM)1997) Influência de Cultivar e Nível de Infestação de *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) no Rendimento do Sorgo. An. Soc. Entomol. Brasil 26: 407-410. https://doi.org/10.1590/S0301-80591997000200028

Crubelati-Mulati NCS, Baleroni AG, Contreras-Soto RI, Ferreira CJB, Castro CR, Albuquerque FAA, Scapim CA (2019) Evaluation of resistance to *Spodoptera frugiperda* in sweet and field corn genotypes. Maydica 64: 1-7.

Cruz, I., (2000). Métodos de criação de agentes entomófagos de *Spodoptera frugiperda* (J.E. Smith). In: Bueno, V.H.P. (Ed.), Controle Biológico de Pragas: Produção Massal e Controle de Qualidade. Universidade Federal de Lavras, Lavras, pp. 112–114.

Cruz I, Turpin FT (1982) Efeito da *Spodoptera frugiperda* em diferentes estádios de crescimento da cultura de milho. Pesq. agropec. Bras 17: 355-359.

Cruz I, Bianco R, Redoan ACM (2016) Potential risk of losses in maize caused by *Dichelops melacanthus* (Dallas) (Hemiptera: Pentatomidae) in Brazil. RBMS 3: 386-397. https://doi.org/10.18512/1980-6477/rbms.v15n3p386-397

Davis FM, Williams WP (1992) Visual rating scales for screening whorl-stage corn for resistance to fall armyworm. (No. Technical Bulletin 186). Mississippi State University, MS39762, USA.

Duarte MM, Ávila CJ, Santos V (2015) Danos e nível de dano econômico do percevejo barriga verde na cultura do milho**.** RBMS 14: 291-299. http://dx.doi.org/10.18512/1980-6477/rbms.v14n3p291-299

Fao. Sorghum and millets in human nutrition. Rome (1995) FAO. Food and Nutrition Series, 27. Disponível em: <http://www.fao.org/docrep/T0818E/ T0818E00.htm>. Acesso em: 09 jun. 2020.

Gallo D, Nakano O, Silveira Neto S, Carvalho RPL, Batista GC de, Berti filho E, Parra JRP, Zucchi RA, Alves SB, Vendraminm JD, Marc Hini LC, Lopes JRS, Omoto C (2002) Entomologia agrícola, Piracicaba: FEALQ, 920p.

Gatehouse JA (2002) Plant resistance towards insect herbivores: a dynamic interaction. New Phytologist 156: 145-169. https://doi.org/10.1046/j.1469-8137.2002.00519.x

Gassen DN (1996) Insetos associados à cultura do trigo no Brasil. Passo Fundo: Embrapa- CNPT (Circular Técnica, 3). GASSEN, D.N. Manejo de pragas associadas à cultura do milho. Passo Fundo: Embrapa- Aldeia Norte. 134p.

Goergen G, Kumar PL, Sankung SB, Togola A, Tamo M (2016) First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (J E Smith) (Lepidoptera, Noctuidae), a New Alien Invasive Pest in West and Central Africa. PLoS One 11: e016563. https://doi.org/10.1371/journal.pone.0165632

Gonçalves AL, Nazaret AMP, Leite NA, Santos CA, Araújo OG, Mendes SM (2011) Adaptação de *Spodoptera frugiperda* O.E Smith, 1797) (Lepidoptera: Noctuidae) em diferentes genótipos de sorgo sacarino. In: III Simpósio de Entomologia, 01 a 05 de Agosto de 2011, Viçosa, MG.

Grigolli JFJ, Grigolli MMK, Lourenção ALF, Gitti D de C (2016) Estratégias de controle químico do percevejo barriga-verde *Dichelops melacanthus* (Dallas) (heteroptera: Pentatomidae) no sistema de sucessão soja e milho safrinha. In: Congresso nacional de milho e sorgo, 31. Bento Gonçalves. Milho e sorgo: inovações, mercados e segurança alimentar: anais. Sete Lagoas: Associação Brasileira de Milho e Sorgo.

Hayden JE (2012) Mexican rice borer, Eoreuma loftini (Dyar) (Lepidoptera: Crambidae: Crambinae) in Florida. Pest Alert. Florida Department of Agriculture and Consumer Services, Division of Plant Industry, FL 2p.

Hammer O, Harper DAT, Ryan PD (2018) PAST: Paleontological Statistics software package for education and data analysis. Paleontol Electronica, v. 4, n. 1, art. 4: 9pp., 178kb. Versão: PAST 3.18.

IBGE (2020) Instituto Brasileiro de Geografia e Estatística, 2020. https://www.ibge.gov.br/) Disponível em: https://agenciadenoticias.ibge.gov.br/agencia-sala-de-imprensa/2013-agencia-de-noticias/releases/27911-em-maio-ibge-preve-alta-de-1-8-na-safra-de-graos-de-2020. Acesso em: 09 jun. 2020.

Knolhoff LM, Heckel DG (2013) Behavioral assays for studies of host plant choice and adaptation in herbivorous insects. Annu. Rev. Entomol 59: 263-278. https://doi.org/10.1146/annurev-ento-011613-161945

Kogan M, Ortman EE (1978) Antixenosis- a new term proposed to replace Painter´s “nonpreference” modality of resistance. Bull. Ent. Soc.Amer 24: 175-176. https://doi.org/10.1093/besa/24.2.175

Lara FM, Foss MRDA, Boiça Junior AL, Trigo JG (1997) Resistência de genótipos de sorgo a *Contarinia sorghicola* (Coq.) (Diptera: Cecidomyiidae) e *Diatraea saccharalis* (Fabr.) (Lepidoptera: Pyralidae) e influência sobre parasitoides. An. Soc. Entomol. Bras 26: 327-333. https://doi.org/10.1590/S0301-80591997000200015

Lara FM (1991) Princípios de Resistência de plantas a insetos. São Paulo Ícone 336 p.

Lara FM, Perussi EM (1984) Resistência de sorgo sacarino *Sorghum bicolor* (L.) Moench ao ataque de *Diatraea saccharalis* (Fabr., 1794). Ciênc. Cult 36: 280-286. https://doi.org/10.1590/S0301-80591997000200015

Legaspi JC, Saldana RR, Roseff N (1997) Identifying and managing stalkborers on Texas sugarcane. Texas Agricultural Experiment Station Publication MP-1777, College Station, TX.

López J, Pitre HN, Meckenstock DH (2000) Influence of nitrogen fertilizer on resistance to fa1larmyworm (Lepidoptera: Noctuidae) in tropical Honduran landrace sorghum. Ceiba 41: 35-39.

magalhães PC, Durães FOM, Rodrigues JAS (2003) Fisiologia da Planta de Sorgo- Comunicado Técnico 86 SSN 1679-0162, Embrapa Milho e Sorgo, Sete Lagoas- MG, p.4.

Martino HSD, Cardoso L de M, Moraes EA, Santana HMP, Queiroz VAV (2014) Por que utilizar o sorgo na alimentação humana? In: Karam D, Magalhães PC (Ed.) Eficiência nas cadeias produtivas e o abastecimento global. Sete Lagoas: Associação Brasileira de Milho e Sorgo cap. 11, p. 95-114.

Mendes SM, Boregas KGB, Lopes ME, Waquil MS, Waquil JM (2011) Respostas da lagarta-do-cartucho a milho geneticamente modificado expressando a toxina Cry 1Ab. Pesq agropec bras 46:239-244 https://doi.org/10.1590/S0100-204X2011000300003

Mendes SM, Viana PA, Cruz I, Waquil JM (2012) Controle de Pragas. In: A. May FO M, Durães IA, Pereira Filho RE, Schaffert RE, Parrella RA da C (Eds.), Sistema Embrapa de produção de sorgo para bioetanol: Sistema BRS1G—Tecnologia Qualidade Embrapa. Sete Lagoas: Embrapa Milho e Sorgo.

Mendes SM, Waquil JM, Rodrigues JAS, Sampaio MV, Viana PA (2014) Manejo de pragas na cultura do sorgo. Informe Agropecuário, Belo Horizonte, v. 35, n. 278, p. 89-99.

Menezes CB, Santos CV, Júlio MPM, Silva KJ, Saldanha DC, Tuma E, Silva CH, Tardin FD, Rodrigues JAS (2015). Capacidade combinatória de linhagens de sorgo granífero cultivados em segunda safra. Boletim de Pesquisa e Desenvolvimento 127, Embrapa Milho e Sorgo, Sete Lagoas.

Milligan SB, Balzarini M, White WH (2003) Broad-sense heritabilities, genetic correlations, and selection indices for sugarcane borer resistance and their relation to yield loss. Crop Science 43: 1729-1735. https://doi.org/10.2135/cropsci2003.1729

Nikpay A (2016) Evaluation of varietal resistance of commercial sugarcane varieties to stalk borers, Sesamia spp. (Lepidoptera: Noctuidae), under field conditions. Acta entomol. sin 57: 785-790. 10.16380/j.kcxb.2016.07.011

Pimentel GV, Tomaz AC, Brasileiro BP, Peternelli LA, Barbosa MHP (2017) Oviposition preference and larval performance of sugarcane borer in eight sugarcane genotypes. Ciênc. Agrotec. 41: 439-446. https://doi.org/10.1590/1413-70542017414004317

Pimentel MAG, Mendes SM, Menezes CB, Oliveira IR, Ramos GCP, Fernandes DKS (2018) Escolher o Híbrido Certo Ajuda a Controlar o Caruncho nos Grãos de Sorgo? Boletim de pesquisa e desenvolvimento 172, 22p. Embrapa Milho e Sorgo Sete Lagoas, MG.

R Core Team (2014). A language and environment for statistical computing. R Foundation for statistical computing. Vienna. New Delhi, India, p 977.

Robertson JB, Van Soest PJ (1981) The detergent system of analysis and its application to humam foods, In: WPT James, O. Theander (Eds.), The analysis of dietary fiber in food, Marcel Dekker, New York, pp. p123–158.

Roza-Gomes MF, Salvadori JR, Pereira PRVS, Panizzi AR (2011) Injúrias de quatro espécies de percevejos pentatomídeos em plântulas de milho. Ciênc. Rural 4: 1-5. :10.1590/S0103-84782011005000081

Rossetto CJ, Banzatto NV, Igue T (1976) Comportamento de veriedades de sorgo em relação a *Contarinia sorghicola* e *Rhopalosiphum maidis* em diferentes épocas de plantio. Bragantia 35: 365-374. https://doi.org/10.1590/S0006-87051976000200010

Rossetto CJ, Igue T (1983) Herança da resistência da variedade de sorgo AF-28 a *Contarinia Sorghicola* Coquillet. Bragantia 42: 211-219. https://doi.org/10.1590/S0006-87051983000100019

Santos FG, Casela CR, Waquil JM (2005) Melhoramento de Sorgo. In: BORÉM, A. Melhoramento de espécies cultivadas. Viçosa: Editora UFV – Universidade Federal de Viçosa. 2ª ed., p.605-658.

Silva AG, Barros ASB, Silva LHCP, Moraes EB, Pires R. Teixeira IR (2009) Avaliação de cultivares de sorgo granífero na safrinha no sudoeste do estado de Goiás. Pesqui. Agropecu. Trop. 39: 168-174.

Silva DD da, Cota LV, Costa RV da, Parreira DF (2014) Principais doenças do sorgo. Informe Agropecuário, Belo Horizonte, v. 35, n. 278, p. 102-111.

Souza JR, Boiça Júnior AL, Perecin D, Costa JT, Ribeiro ZA (2017) Não preferência para oviposição e alimentação da broca-da-cana por cultivares de cana-de-açúcar. Amaz. J. Agric. Environ. Sci. 60: 291–295.

Sturza VS, Cunha US, Bernardi D, Greco MGCE, Nava DE (2020) Nonpreference for Oviposition of Sugarcane Borer (Lepidoptera: Crambidae) in Sugarcane Seedlings is influenced by ripening group and plant age. Environ. Entomol. 49: 1-7. https://doi.org/10.1093/ee/nvaa039

Tomaz AC, Coutinho AE, Soares BO, Peternelli LA, Pereira EJG, Barbosa MHP (2017) Assessing resistance of sugarcane varieties to sugar cane borer *Diatraea saccharalis* Fab. (Lepidoptera: Crambidae). Bull. Entomol. Res 108: 547-555. https://doi.org/10.1017/S0007485317001183[Opens in a new window]

Vilela M, Mendes SM, Viana PA (2014) Manejo de pragas do sorgo. Jornal Eletrônico da Embrapa Milho e Sorgo (Sete Lagoas-MG), Ano 08 - Edição 57.

Vilela M, Santos AJN dos, Simeone MLF, Parrella RA da C, Silva D D da, Parreira D F, Okumura F, Schaffert R E, Mendes S M (2017) Influence of *Diatraea saccharalis* (Lepidoptera: Crambidae) infestation on sweet sorghum productivity and juice quality. Afr. J. Agric. Res. 12: 2877-2885 10.5897/AJAR2017.12431

Waquil JM, Santos JP, Lordelo AIL, Schaffert RE, Santos FG, Vencovsky R, Oliveira AC (1980) Comportamento de cultivares de sorgo sacarino em relação à broca-da-cana-de-açúcar, *Diatraea saccharalis* (F. 1794) em condições de campo. In: Anais VI CBE/SEB/Campinas, SP. 3 a 9/02/80, R. 108.

Waquil JM, Santos TM (1990) Avaliação de cultivares de sorgo em relação à lagarta-do-cartucho, *Spodoptera frugiperda*. In: Anais do 18º Congresso Nacional de Milho e Sorgo. Realizado de 29/julho a 03/agosto de 1990, Vitória, ES. p. 88.

Waquil JM (2001) Resistance of commercial hybrids and lines of sorghum, *Sorghum bicolor* (L.) Moench., to *Diatraea saccharalis* (Fabr.) (Lepidoptera: Pyralidae). Neotrop. Entomol. 30: 661-668. https://doi.org/10.1590/S1519-566X2001000400022

Waquil JM, Viana PA, Cruz I (2003) Manejo de pragas na cultura do sorgo. Circular Técnica. Embrapa Milho e Sorgo, Sete Lagoas, v. 27, 25p.

White WH (1993) Cluster analysis for assessing sugarcane borer resistance in sugarcane line trials. Field crops res. 33: 159-168. https://doi.org/10.1016/0378-4290(93)90099-9

White WH, Hale AL, Veremis JC, Tew TL, Richard EP (2011) Registration of two sugarcane germplasm clones with antibiosis to the sugarcane borer (Lepidoptera: Crambidae). J. Plant Regist. 5: 248-253. https://doi.org/10.3198/jpr2010.07.0429crg

White WH, Miller JD, Milliga NSB, Burner DM, Legendre BL (2001) Inheritance of sugarcane borer resistance in sugarcane derived from two measures of insect damage. Crop Sci. 41: 1706-1710. https://doi.org/10.2135/cropsci2001.1706

Table 1. Mean (±SE) injury scores (1 to 9) caused by *Spodoptera frugiperda* larvae on grain sorghum hybrids at 7, 14 and 21 days after infestation (DAI).

HÍBRIDOS	7 dias	14 dias	21 dias
1G100	7,11 ± 0,11	8,56 ± 0,44	9,00 ± 0,00
1G220	7,11 ± 0,11	8,89 ± 0,11	9,00 ± 0,00
1G233	6,44 ± 0,29	8,22 ± 0,22	8,78 ± 0,11
1G244	7,89 ± 0,29	9,00 ± 0,00	9,00 ± 0,00
50A10	7,89 ± 0,40	9,00 ± 0,00	9,00 ± 0,00
50A40	8,11 ± 0,11	8,56 ± 0,44	8,89 ± 0,11
50A70	7,11 ± 0,68	8,33 ± 0,67	8,44 ± 0,56
70G70	7,44 ± 0,29	8,67 ± 0,19	9,00 ± 0,00
80G20	7,11 ± 0,40	8,56 ± 0,22	9,00 ± 0,00
A6304	7,00 ± 0,19	9,00 ± 0,00	9,00 ± 0,00
A9721R	6,89 ± 0,11	8,22 ± 0,22	9,00 ± 0,00
A9735R	6,33 ± 0,69	6,78 ± 1,90 **	7,00 ± 2,00 **
A9902	7,89 ± 0,48	9,00 ± 0,00	9,00 ± 0,00
AG1080	7,33 ± 0,19	8,22 ± 0,11	9,00 ± 0,00
AG1090	6,78 ± 0,22	8,44 ± 0,29	8,89 ± 0,11
AS1615	7,67 ± 0,38	8,44 ± 0,29	9,00 ± 0,00
BRAVO	7,11 ± 0,11	8,44 ± 0,29	8,89 ± 0,11
BRS373	3,11 ± 1,57 ***	3,89 ± 1,95 ***	5,44 ± 2,00 ***
BUSTER	8,22 ± 0,11	9,00 ± 0,00	9,00 ± 0,00
DKB550	7,89 ± 0,44	8,78 ± 0,22	9,00 ± 0,00
DKB590	7,22 ± 0,22	8,78 ± 0,22	8,89 ± 0,11
ENFORCER	7,56 ± 0,40	8,78 ± 0,22	9,00 ± 0,00
JADE	7,78 ± 0,40	9,00 ± 0,00	9,00 ± 0,00
MSK321	6,89 ± 0,48	8,00 ± 0,33	8,78 ± 0,22
MSK326	7,11 ± 0,80	8,89 ± 0,11	9,00 ± 0,00
MSK327	5,33 ± 1,95 **	6,67 ± 1,84 **	7,67 ± 1,33
XB6022	7,67 ± 0,19	9,00 ± 0,00	9,00 ± 0,00
XGN1305	7,22 ± 0,78	8,67 ± 0,33	9,00 ± 0,00
MSK320	7,56 ± 0,56	8,44 ± 0,56	8,78 ± 0,22
FOX ATLÂNTICA	7,11 ± 0,40	8,89 ± 0,11	9,00 ± 0,00

Asterisks refer to significance. Means followed by *** = highly significant, ** significant and no asterisk = low significance, ns= not significant by the Tukey test ($P < 0.05$).

Table 2. Means (±SE) of numbers healthy and bored internodes, gallery length (cm) and caused by *Diatraea saccharalis* in grain sorghum hybrids. I.I = infestation intensity.

Hybrids	Healthy internodes	Bored internodes	Galleries (cm)	I.I (n.s)
1G100	4,11 ± 0,44	0,78 ± 0,29	2,89 ± 0,39	13,36 ± 3,72
1G220	5,44 ± 0,78 **	0,00 ± 0,00	0,00 ± 0,00	0,00 ± 0,00
1G233	4,33 ± 0,67	0,22 ± 0,11 **	4,33 ± 2,19	7,14 ± 4,96
1G244	3,89 ± 0,59	0,44 ± 0,11	4,50 ± 1,26	11,11 ± 4,24
50A10	3,56 ± 0,40	0,56 ± 0,11	4,00 ± 0,29	13,33 ± 3,26
50A40	3,11 ± 0,40	0,78 ± 0,11	2,56 ± 0,06	18,52 ± 1,85
50A70	1,00 ± 0,69 ***	1,56 ± 0,29	12,83 ± 0,05 ***	64,81 ± 20,87
70G70	3,56 ± 0,11	0,44 ± 0,11	4,67 ± 0,88	13,33 ± 2,55
80G20	5,11 ± 0,80	0,00 ± 0,00	0,00 ± 0,00	0,00 ± 0,00
A6304	1,89 ± 0,29 ***	1,00 ± 0,19	11,08 ± 0,74 **	33,33 ± 6,42
A9721R	6,67 ± 0,58 ***	1,00 ± 0,33	4,14 ± 0,18	12,59 ± 2,63
A9735R	4,67 ± 0,58	0,33 ± 0,00 **	3,67 ± 0,33	5,29 ± 0,26
A9902	5,56 ± 0,29 **	1,00 ± 0,33	2,89 ± 0,11	14,52 ± 4,73
AG1080	3,89 ± 0,29	0,67 ± 0,00	4,08 ± 0,36	15,00 ± 0,00
AG1090	4,00 ± 0,51	0,00 ± 0,00	0,00 ± 0,00	0,00 ± 0,00
AS1615	5,33 ± 1,53 **	0,00 ± 0,00	0,00 ± 0,00	0,00 ± 0,00
BRAVO	4,89 ± 0,40	0,00 ± 0,00	0,00 ± 0,00	0,00 ± 0,00
BRS373	3,44 ± 0,44	0,00 ± 0,00	0,00 ± 0,00	0,00 ± 0,00
BUSTER	4,00 ± 0,58	1,78 ± 0,56 ***	4,74 ± 0,38	29,59 ± 8,56
DKB550	2,33 ± 0,19	0,78 ± 0,11	3,61 ± 0,45	24,07 ± 4,90
DKB590	4,00 ± 0,84	0,89 ± 0,40	5,86 ± 0,58 **	22,41 ± 10,20
ENFORCER	5,78 ± 0,87 **	0,89 ± 0,40	3,42 ± 0,79	12,79 ± 6,75
JADE	2,89 ± 0,22	0,67 ± 0,00	8,83 ± 0,93 **	19,44 ± 1,60
MSK321	2,33 ± 0,38	1,22 ± 0,40	3,25 ± 0,43	37,96 ± 14,55
MSK326	2,89 ± 0,11	0,44 ± 0,11	4,67 ± 0,67	14,81 ± 3,34
MSK327	4,00 ± 0,38	0,33 ± 0,00 **	2,50 ± 0,14	7,22 ± 0,56
XB6022	5,11 ± 0,95	0,89 ± 0,22	4,44 ± 0,29	16,22 ± 4,65
XGN1305	3,56 ± 1,09	0,89 ± 0,40	3,33 ± 1,76	23,61 ± 13,68
MSK320	5,56 ± 0,68 **	0,22 ± 0,11 **	7,08 ± 0,74	4,07 ± 2,06
FOX ATLÂNTICA	2,89 ± 0,29	1,22 ± 0,29	5,64 ± 0,07 **	28,52 ± 6,46

Asterisks refer to significance. Means followed by *** = highly significant, ** significant and no asterisk = low significance, ns= not significant by the Tukey test ($P < 0.05$).

Table 3. Mean (±SE) injury scores (1 to 4) of *Diceraeus melacanthus* in grain sorghum hybrids at 12, 19, and 26 days after infestation (DAI) by adult stinkbug.

Hybrids	**12 DAI** (n.s)	**19 DAI** (n.s)	**26 DAI** (n.s)
1G100	2.00 ± 0.33	2.33 ± 0.88	2.00 ± 1.00
1G220	2.33 ± 0.00	2.33 ± 0.33	2.00 ± 0.00
1G233	2.33 ± 0.33	2.00 ± 0.58	1.33 ± 0.33
1G244	1.33 ± 0.33	1.33 ± 0.33	1.33 ± 0.33
50A10	1.00 ±0.33	1.00 ± 0.00	1.00 ± 0.00
50A40	0.33 ± 0.33	0.33 ± 0.33	0.33 ± 0.33
50A70	2.33 ± 0.67	1.67 ± 0.33	1.33 ± 0.33
70G70	2.67 ± 0.67	2.33 ± 0.33	1.67 ± 0.67
80G20	3.67 ± 0.67	3.67 ± 0.33	3.67 ± 0.33
A6304	2.33 ± 0.33	2.33 ± 0.67	2.00 ± 0.58
A9721R	2.67 ± 0.33	1.67 ± 0.67	1.33 ± 0.33
A9735R	0.67 ± 0.67	0.33 ± 0.33	0.33 ± 0.33
A9902	2.33 ± 0.33	2.33 ± 0.33	1.33 ± 0.33
AG1080	2.67 ± 0.33	2.33 ± 0.33	2.00 ± 0.00
AG1090	1.67 ± 0.33	1.33 ± 0.33	1.33 ± 0.33
AS1615	1.33 ± 0.00	1.33 ± 0.33	1.33 ± 0.33
BRAVO	2.67 ± 0.58	2.33 ± 0.33	2.33 ± 0.33
BRS373	2.33 ± 0.33	2.67 ± 0.67	2.33 ± 0.88
BUSTER	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00
DKB550	2.00 ± 0.00	2.00 ± 0.58	1.00 ± 0.58
DKB590	2.33 ± 0.33	1.33 ± 0.33	1.33 ± 0.33
ENFORCER	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00
JADE	1.00 ± 0.33	1.00 ± 0.00	1.00 ± 0.00
MSK321	2.67 ± 0.33	2.67 ± 0.33	2.00 ± 0.58
MSK326	4.00 ± 0.33	3.67 ± 0.33	3.33 ± 0.33
MSK327	1.67 ± 0.33	1.67 ± 0.33	1.67 ± 0.33
XB6022	2.33 ± 0.33	1.67 ± 0.33	1.67 ± 0.33
XGN1305	2.33 ± 2.33	2.00 ± 0.00	2.00 ± 0.00
MSK320	2.33 ± 2.33	2.00 ± 0.00	2.00 ± 0.00
FOX ATLÂNTICA	1.33 ± 1.33	1.33 ± 0.33	1.00 ± 0.00

ns= not significant by the Tukey test ($P < 0.05$).

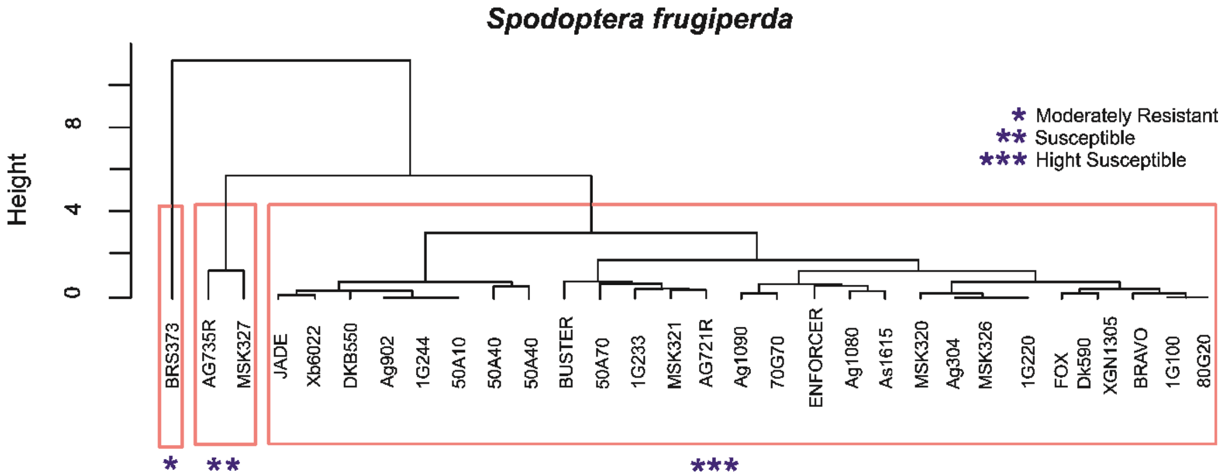

Fig 1 Dendrogram of the cluster analysis based on the Euclidean distance and grouping by means of UPGMA, in terms of damage scores by *Spodoptera frugiperda* larvae on grain sorghum hybrids at 7 and 14 days after infestation

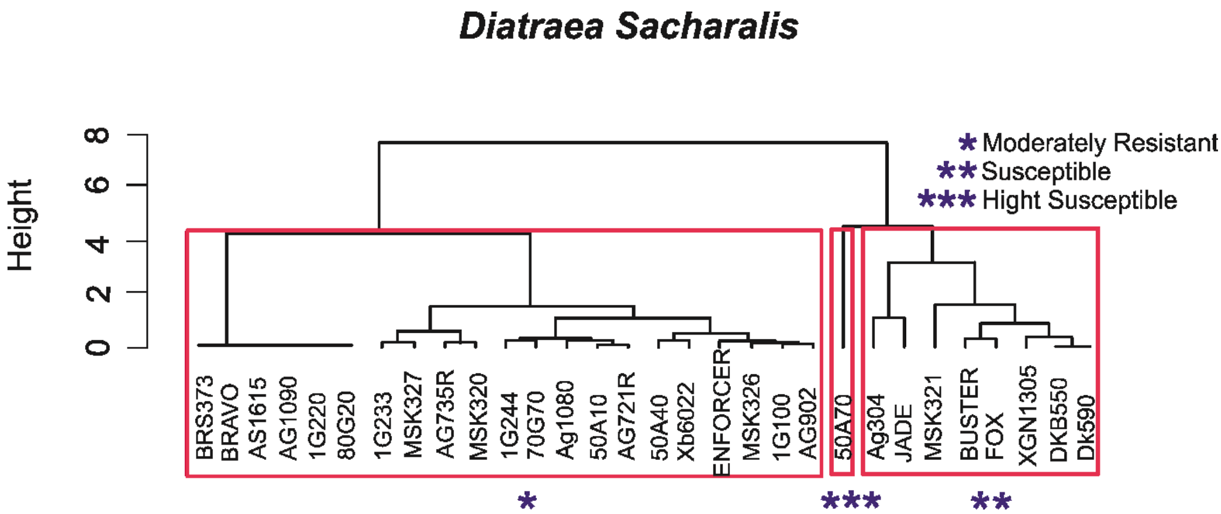

Fig. 2 Dendrogram of the cluster analysis based on the Euclidean distance and grouping by means of UPGMA, in terms of numbers healthy and bored internodes, gallery length and infestation intensity by *Diatraea saccharalis* in grain sorghum hybrids

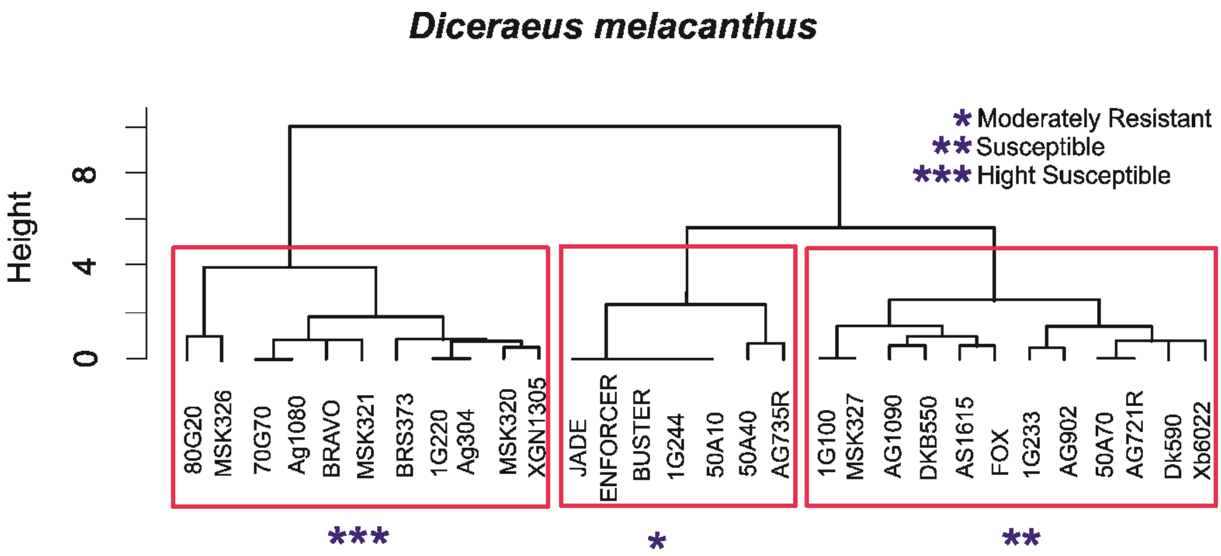

Fig. 3 Dendrogram of the cluster analysis based on the Euclidean distance and grouping by means of UPGMA, in terms damage scores of *Diceraeus melacanthus* in grain sorghum hybrids at 12, 19, and 26 days after infestation

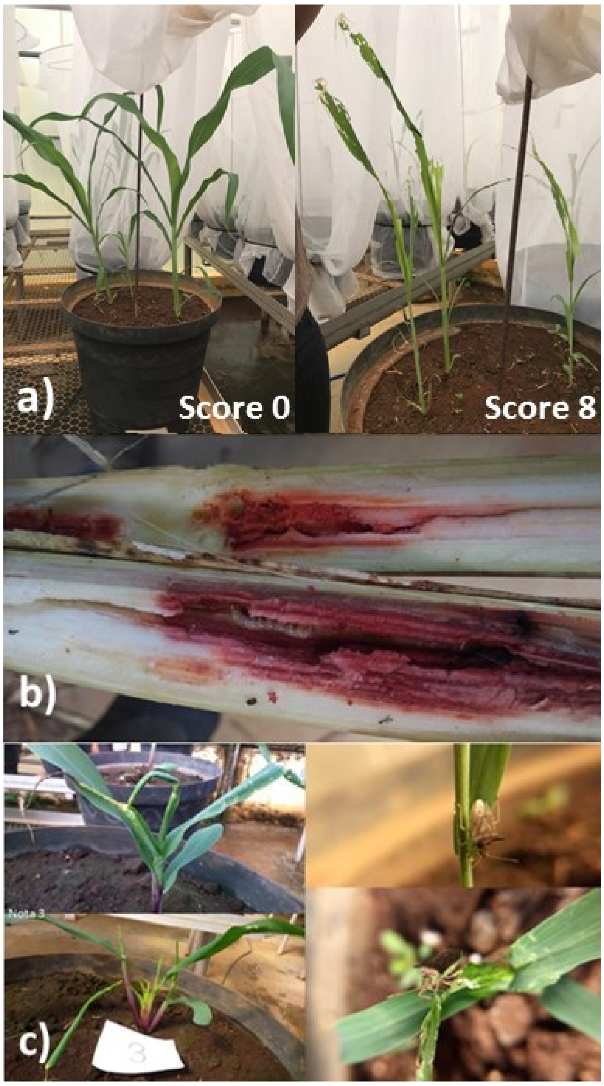

Figure 4. Scores on sorghum plants caused by *S. frugiperda* (a); *D. saccharalis* (b); and *D. melacanthus* (c)

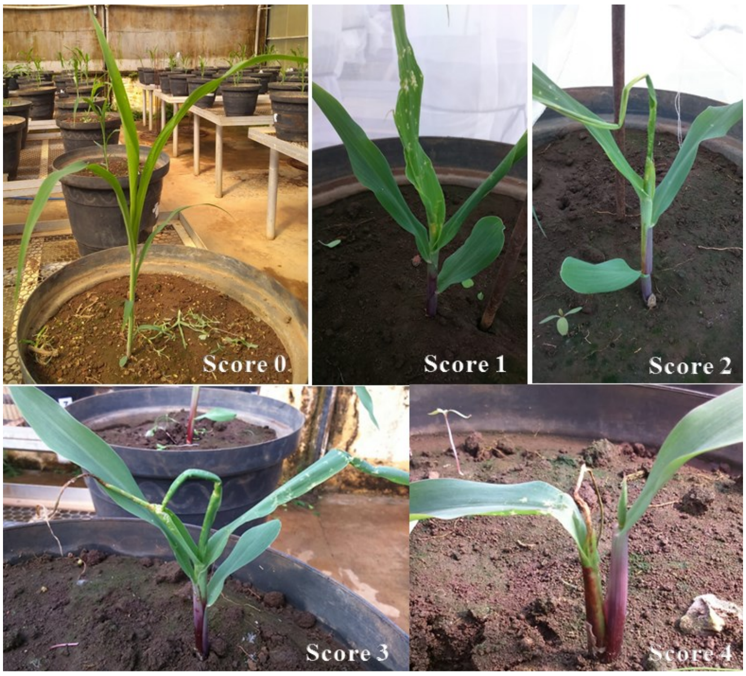

Figure 5- Green-belly stinkbug injury based on the damage score scale adapted by Roza-Gomes et al. (2011) (0-4) to maize injury