Ciências Agrárias
SEMINA

DOI: 10.5433/1679-0359.2024v45n6p1733

Euschistus heros: Economic injury level and economic threshold of early maturing carioca common bean cultivar

Euschistus heros: Nível de dano econômico e nível de controle para cultivar precoce de feijão carioca

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Highlights

The neotropical brown stink bug diminishes the common bean grain quality.
The healthy grain yield decreased by 11% in the summer and 6% in the rainy season.
The EIL was 1.42 and 1.07 stink bug m^{-1} in the summer and rainy season, respectively.

Abstract

Early maturing common-bean cultivars lack information referring to *Euschistus heros* (Fabricius, 1798) (Hemiptera: Pentatomidae) feeding damage assessment. This information is pertinent towards establishing economic threshold for an integrated pest management program. The aim of this study was to analyze the relationship, between the density of stink bugs and the degree of injuries towards the pod and grain production, quantity and quality, of the IPR Curió cultivar. The experiments were conducted during two seasons at the IDR-Paraná in Londrina, Paraná, in field conditions. The experimental design was randomized blocks with five repetitions. The treatments were: 0 (control); 1; 2; 3; 4; 5 *E. heros* m^{-1}. The evaluated variables were number of grained and flat pods; healthy, damaged and aborted grain mass; grain yield. The economic injury level (EIL), economic threshold (ET) and spraying efficiency influence on the ET were calculated. The total number of grained pods was not affected. More than three brown stink bugs, during the summer season, significantly increases flat pod output. The rainy season resulted in

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Received: Dec. 04, 2023 Approved: Sept. 02, 2024

greater aborted grains. Increasing *E. heros* densities, during the summer season, significantly reduces the healthy grain output. The damaged grain mass doubles at higher than one *E. heros* population densities. The total grain mass produced was not affected. During the summer season, each *E. heros* reduces 11% of healthy grain output, and during the rainy season 6%. During the summer season was 1.50 of *E. heros* m^{-1} and for the rainy season 1.00 *E. heros* m^{-1}. The spraying efficiency should directly affect the EIL, modifying the value, thus better resembling the field conditions.
Key words: Control cost. Neotropical brown stink bug. *Phaseolus vulgaris* L.. Sucking insects.

Resumo

Cultivares precoces de feijão carecem de maiores informações sobre a quantificação dos danos provocados pela alimentação de *Euschistus heros* (Fabricius, 1798) (Hemiptera: Pentatomidae). Estas informações possibilitam estabelecer o nível de dano econômico para um programa de manejo integrado de pragas. O objetivo deste estudo foi de definir a relação entre diferentes densidades de percevejo e o grau de injuria na quantidade e qualidade da produção de vagens e grãos da cultivar IPR Curió. Os experimentos foram conduzidos durante duas safras no IDR-Paraná, em Londrina, Paraná, sob condição de campo. O delineamento experimental utilizado foi de blocos casualizados com cinco repetições. Os tratamentos foram: 0 (controle); 1; 2; 3; 4; 5 *E. heros* m^{-1}. As variáveis avaliadas foram: número de vagens granadas e chochas; massa de grãos saudáveis, danificados e abortados; produtividade. O nível de dano econômico (NDE), nível de controle (NC) e influência da eficiência de aplicação sobre o NC foram calculados. Mais de três percevejos marrom, durante a safra da seca, aumenta significativamente a quantia de vagens abortadas. A massa de grãos danificados duplica em densidades acima de um *E. heros*. A massa total de grãos produzidos não é afetada por densidades crescentes de percevejo marrom. Durante a safra das águas cada *E. heros* tem potencial de reduzir até 6% da produção de grãos saudáveis, durante a safra da seca, tem potencial de reduzir até 11%. O NC durante a safra da seca e águas foi determinado em 1.50 e 1.00 *E. heros* m^{-1}, respectivamente. A eficiência de aplicação deveria influenciar diretamente o NDE, modificando seu valor, visando representar melhor as condições de campo.
Palavras-chave: Custo de controle. Percevejo marrom. *Phaseolus vulgaris* L.. Insetos sugadores.

Introduction

The common bean is affected by pest insects throughout its development, highlighted are the defoliation and sucking arthropods (Quintela 2001, 2009; Quintela & Barbosa, 2015; Barbosa et al., 2021). The pest insects' damage varies depending on the cultivation season, due to, climate conditions, cultivars, and cultivation practices (Hohmann & Carvalho, 1983; Barbosa et al., 2017). Within the sucking Arthropoda there are mites, thrips and stink bugs (Quintela 2001, 2009; Quintela & Barbosa, 2015; Barbosa et al., 2021). With an emphasis on the neotropical brown stink bug [*Euschistus heros* (Fabricius) 1798] (Hemiptera: Pentatomidae), the damage caused by this insect is related to its feeding habits (sucking apparatus), causing direct damage to the pods and, consequently, the grains, resulting in smaller, wrinkled and damaged grains (Quintela & Barbosa, 2015; Barbosa et al., 2021). The stink bug's feeding may also affect the seed quality due to germinative potential reduction (Flor et al., 2004). However, there is also indirect damage caused from the resulting damaged tissues, which serve as pathogen pathways, pathogens such as *Nematospora corylli* (Peglion & Kurtzaman), that is responsible for grain depreciation during commercial classification (Rosolem & Marubayashi, 1994; Ministério da Agricultura, Pecuária e Abastecimento [MAPA], 2019).

The integrated pest management (IPM) program was first discussed by Stern et al. (1959), who proposed an objective system. This has been through the years further explored resulting in the conception of the house analogy for soybean IPM, which base represents the IPM decision making strategies and whose pillars represent the management strategies (Bortolotto et al., 2015; Maciel & Freitas Bueno, 2022). An adequate pest control should consider insect population fluctuations during sampling, when this population reaches the economic threshold (ET), which represents the specified moment or population density before the pest's production depreciation equals its control cost, this is also known as economic injury level (EIL) (Stern et al., 1959; Higley & Peterson, 2009).

Euschistus heros management in common bean is mostly through insecticide spraying following previously determined soybean ET, which are: during grain development the ET is two stink bugs m^{-1}, when the production is grain focused, but one stink bug m^{-1} if the production is seed focused (Bueno et al., 2013). Given the common bean cultivars' varied growth habits, the EIL and ET may be influenced when considering determinate or indeterminate growth habits and should be further analyzed.

Different pesticide spraying strategies are available, such as tractor implements, manual carried hydraulic sprayer, aerial application and drone spraying, each with benefits and drawbacks, regarding cost, time consumption, qualified labor and effective covering area (Matthews et al., 2008; Ahmad et al., 2021). Nansen and Ridsdill-Smith (2013), considered that the chosen spraying strategy is the greatest cause of low efficiency pest control. There are many variables which also affect efficiency, like spray nozzle configuration, spraying height, spraying speed, adjuvant and especially pest behavior, varying between terrestrial or aerial habits (Chaim 2009; Sijs & Bonn, 2020). These factors should also be considered when calculating the EIL and consequently ET.

The neotropical brown stink bug has demonstrated increased occurrences with each common bean harvest in the Paraná State, mainly in the spring and winter harvests, causing considerable damage to the grains (Ramos et al., 2017). Most of the attacks come from the migration of this pest from other crops, mainly from soybean, reaching the common bean crop with great populations (Ramos et al., 2017). Considering the scarcity of information in the literature regarding the ET and EIL for the common bean crop and especially for the colored carioca commercial group, which is the most consumed type in the country. This highlights the importance of this work which objectified to establish the relationship between the density of brown stink bugs during the grain formation and filling period, and the degree of damage towards production and grain quality in carioca common bean from a determinate cycle common bean cultivar.

Material and Methods

Study environment

This study was conducted in two agricultural harvests, one during the summer season of 2019 and the other in the rainy season of 2020/21, at the IDR-Paraná (Instituto de Desenvolvimento Rural do Paraná IAPAR-EMATER) experimental station, in Londrina, Paraná State, with an altitude of 584 meters and the coordinates: latitude 23°21'33.7"S and longitude 51°09'50.2"W. According to the Köppen classification the region is humid subtropical with hot summers (Cfa), with an average annual temperature of 21.1 °C and an average annual precipitation of 1639 mm (Instituto de Desenvolvimento Rural do Paraná [IDR-Paraná], 2022). The soil classification is Rhodic Ferrasol with a very clayey texture (Santos et al., 2018).

Climate conditions

The climatic data were recorded at the meteorological station located at IDR-Paraná experimental station. The summer season of 2019 had a total rainfall of 444.8 mm, with an average temperature of 24.9 °C, maximum average of 31.5 °C and minimum average of 20.4 °C (Figure 1A). There was a vast volume of rainfall for this season, and the greatest amount was during the month of February with a total of 183 mm, which coincided with the common bean flowering period (IDR-Paraná, 2022).

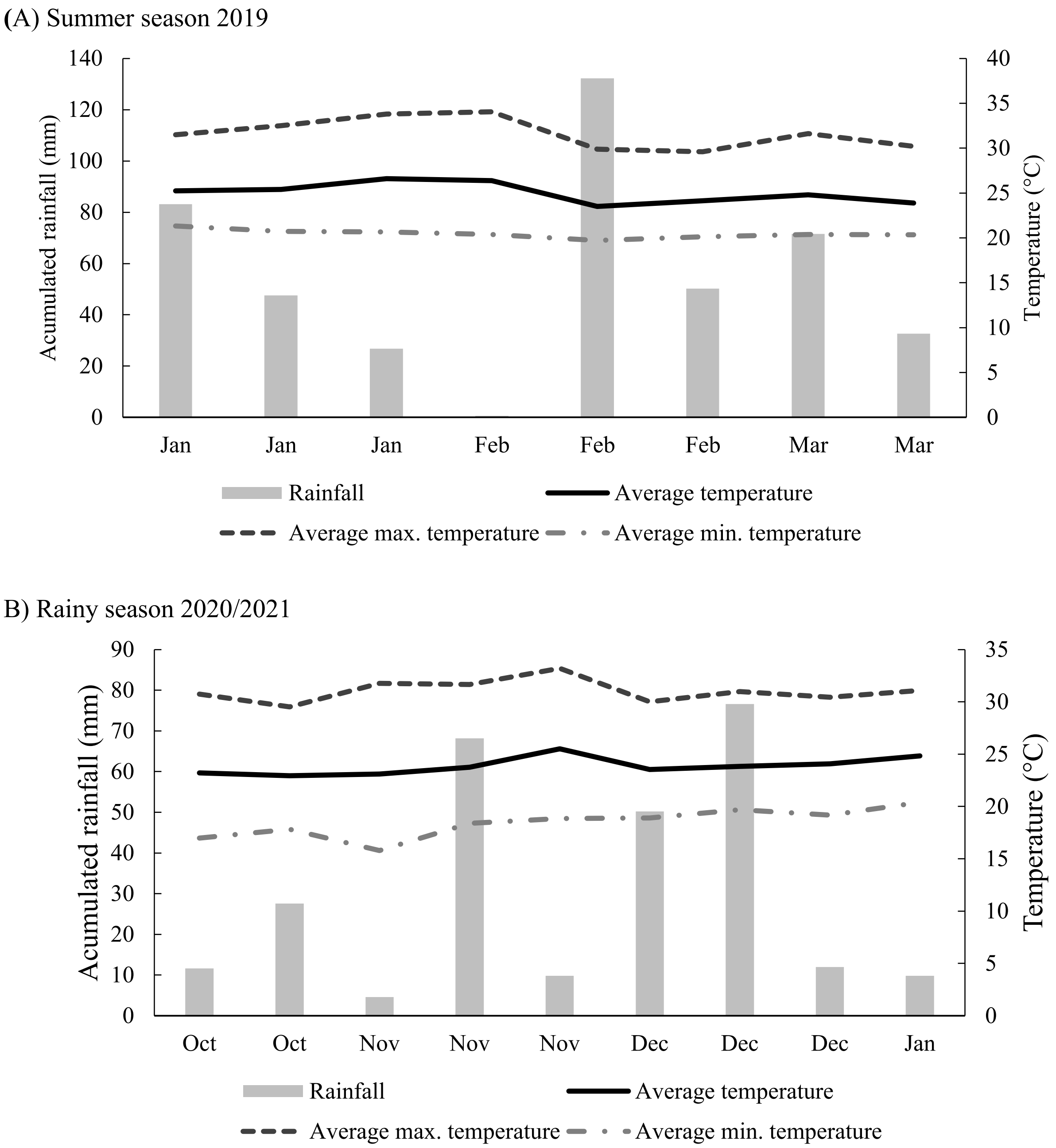

Figure 1. Accumulated rainfall, average temperature and average maximum and minimum temperatures, per ten days, during the cultivation of common bean IPR Curió in the summer season of 2019 and rainy season of 2020/2021.

During the 2020/21 spring (rainy) season there was a total rainfall of 270.4 mm, with an average temperature of 23.9 °C, maximum average of 31 °C and minimum average of 18.4 °C (Figure 1B). The greatest rainfall volume was during the month of December, with 138.8 mm, which coincided with the common bean flowering period (IDR-Paraná, 2022).

Common bean cultivar and crop conditions

The chosen common bean (*Phaseolus vulgaris* L.) cultivar was IPR Curió, released in 2013, a carioca type bean with beige color and light brown stripes. This cultivar is classified as an early cycle and determinate growth type, with an average germination-harvest time of 70 days. It is resistant to common bean rust [*Uromuces phaseoli* (Reben) Wint.] and powdery mildew (*Erysiphe poligoni* DC), mildy resistant towards bacterial blight (*Xanthomonas axonopodis* pv. phaseoli) and bacterial wilt [*Curtobacterium flaccumfaciens* pv. flaccumfaciens (Cff)], and susceptible to anthracnose [*Colletotrichum lindemuthianum* (Sacc. & Magn.) Scrib.] and angular leaf spot [*Isariopsis griseola* (Sacc.)] (IDR-Paraná, 2023).

The soil previously cultivated the cover crop fodder radish (*Raphanus sativus* L. var. oleiformis), which before the experiment's sowing, was shredded using a Tritton shredder model 1800. The designated experimental area's dimensions were 25 × 50 meters, thus 1250 m². Initially a soil analyses was conducted followed by the necessary soil nutrition corrections as recommended for common bean growing by the state (Pavinato et al., 2017).

The common bean cultivar sowing followed the no tillage system with 0.45 m between lines and 0.10 m between plants, resulting in 10 plants per square meter. The seeds were previously treated with fungicide and insecticide. The spontaneous plants were manually controlled using manual weeding throughout both experimental periods.

The summer season assay was sown January 7th and the harvested March 20th, during the year 2019. The spring (rainy) season assay was sown October 19th, 2020 and harvested January 11th, 2021. The plants were harvested when 90% of the plants were in complete physiological maturity, and the pods were later moved to a climate-controlled room (25 °C and 70% RH), followed by grain threshing and separation into treatment codified paper bags of 0.3 m × 0.31 m × 0.19 m (height × width × thickness). These two seasons were chosen as evaluated cropping periods due to their common bean cultivation relevance in the Paraná state.

Euschistus heros origin

The brown stink bugs [*Euschistus heros* (Fabricius, 1798)] were selected from the IDR-Paraná insect rearing laboratory, in Londrina, Paraná State. The insects are reared in a climate-controlled green house (28 ± 4° C, 70 ± 20% RH), with a diet composed of green common-bean pods, soybean (*Glycine max* L.) grains and peanut (*Arachis hypogaea* L.) grains. Adult females with a week of maturity were collected and stored in clear plastic containers of 3.5 cm × 11 cm × 11 cm (height × width × thickness), prior to use in the experiments.

Experimental design

In both evaluated seasons, the 2019 summer season and 2020/21 rainy season, the experiments followed a random block design, composed of five replicants and six treatments. Each block composed of the different *E. heros* population densities per meter: witness (no brown stink bug); one; two; three; four; five stink bugs per linear meter.

At the start of the common-bean plant's flowering (R1), cages of 1.5 m × 1.1 m × 1.1 m (height x width x thickness), composed of metal rods for support, and white anti-aphid polyester fabric (2 mm × 2 mm mesh) for covering, were installed in pre-selected areas of one square meter inside the IPR Curió cultivated area of 1250 m². Six cages were built per block, resulting in 30 cages. The cages were designed with two zippers of one meter height for entrance, each in opposite sides of the cages. The cage's edges were buried with soil to thwart crawling insect entry. Two meters were encaged, containing 10 common bean plants each, totaling 20 plants per cage.

During the full flowering stage (R2), female *E. heros* were released in each treatment as follows: witness (zero); one (two stink bugs); two (four stink bugs); three (six stink bugs); four (eight stink bugs); five (ten stink bugs). Prior to the *E. heros* release, four yellow insect sticky traps, one in each corner of the cage, and manual picking were used to control invasive insects. The traps were removed prior to *E. heros* infestation. The brown stink bugs were carefully released following the designated treatments. The cages were inspected thrice a week and eventual dead *E. heros* were replaced with isolated females of the same age until the end of the experiments. Female *E. heros* were chosen due to their greater feeding frequency when compared to males, this was previously assessed in the insect rearing laboratory of the IDR-Paraná.

Common bean cultivar evaluated variables

The interior plants from each cage were manually harvested and the pods from these ten plants were stored in a paper bag for later evaluation. Prior to grain threshing, the harvested pods were categorized as grained or flat. The grains were separated as healthy (intact tegument, well-formed and with no stains), damaged (morphed tegument, malformed and with stains) and aborted (dark tegument, shriveled and deformed) and later stored in labeled bags. The aborted grains were only tabulated from grained pods, the flat pods' grains were not counted. The grains were then classified for commercial quality standards using gradual sieves (5 cm, 4.5 cm, 4 cm, 3.75 cm and 3.5 cm mesh), following the national #12 normative from the Ministério da Agricultura e Pecuária (MAPA) (Knabben & Costa, 2012). Grains that passed below the 3.5 cm mesh are not considered commercially viable. The classified grains were separated into labeled paper bags for posterior moisture and mass determination.

The grains' moisture was determined using a Gehaka® model G939 IP grain moisture meter, later the grains' mass was determined using the precision scale Marte® model AD1000 1010G. The resulting masses [(healthy or damaged) x (sieve commercial classification)] from each treatment was then transformed into kilograms per hectare (kg ha^{-1}). This was achieved by using the measured mass of each treatment (mass of 20 plants, in grams) and multiplying that value by the number of plants in a hectare. Considering the spacing of 0.45 m between lines and 0.1 m between plants, this amounts to a total of roughly 222,222 plants per hectare. Thus, each treatment mass was multiplied by 222,222 and finally divided by 20,000 (number of plants per cage and kilogram correction). The commercial production reduction (PR) for the *Euschistus heros* infested treatments was then calculated using the following Equation 1:

$$PR\ (\%) = \frac{IP \times 100}{NIP} \quad (1)$$

Where: IP is *E. heros* Infested production (kg ha^{-1}) and NIP is Not Infested Production (kg ha^{-1}).

Statistical analyses

The data were submitted to normality and homoscedasticity tests, followed by variance analysis and regression analysis. These analyses were achieved using the statistics programs R Project (R Core Team, 2021) package AgroReg (Shimizu & Gonçalves, 2022).

Economic injury level and economic threshold

The formula described by Nakano et al. (1981) was used to calculate the damage tolerance percentage (D %). The Equation 2 was used:

$$D\ \% = \frac{Cc \times 100}{V} \quad (2)$$

Where: Cc is the control cost in currency per hectare (Brazilian Real); V is the estimated production value in currency per hectare (Brazilian Real).

The control cost is the sum of operational and spraying costs, and the insecticide market price (Table 1). The operational and spraying values were obtained from a compilation of the state’s common bean farmers’ monthly production costs, collected by the Paraná state’s Secretaria da Agricultura e do Abastecimento (SEAB) and Departamento de Economia Rural (DERAL). This data was provided by the Socioeconomic sector at the IDR-Paraná, Londrina, Paraná State.

Table 1

***Euschistus heros* control cost in Brazilian Real considering *Phaseolus vulgaris* registered insecticides in the Paraná State during the summer season of 2019 and rainy season of 2020/2021**

Season	Brand	Company	Dose (L ha^{-1})	(R$ L^{-1})*	(R$ ha^{-1})
Summer 2019	Fastac Duo	BASF	0.35 L ha^{-1}	166.00 *	83.00
	Incrível **	IHARA	-	-	-
	Operational cost	-	-	-	1078.12 ***
Rainy 2020/2021	Bold	IHARA	0.5 L ha^{-1}	76.08	38.04
	Fastac Duo	BASF	0.35 L ha^{-1}	172.80	60.48
	Maxsan	IHARA	0.87 L ha^{-1}	52.00	45.50
	Operational cost	-	-	-	1085.68 ***

* Average price obtained from agricultural resale stores.
** Insecticide not commercially available.
*** Average operational cost excluding the insecticide, fertilizer and seed costs informed by common bean farmers in the Paraná State to the Departamento de Economia Rural (DERAL), IDR-Paraná, 2019 and 2021.

The spraying cost is formed by taking the dose (liters per hectare) recommendation and converting them to cost per liter (market price) and cost per hectare (market price) (Table 1). The insecticide market prices were obtained from agricultural resale stores from the northern region of Paraná State. In the crop season of 2019, the Agência de Defesa Agropecuária do Paraná (ADAPAR), referred to only two registered insecticides for *E. heros* control in common bean crops. The first, Fastac Duo®, a systemic and contact insecticide composed of acetamiprid (neonicotinoid) and Alpha-Cypermethrin (pyrethroid). The second, Incrível®, also a systemic and contact insecticide with the same chemical compost (Agência de Defesa Agropecuária do Paraná [ADAPAR], 2019). However, the second insecticide was removed from market and thus was unavailable. During the 2020/21 crop season two more insecticides were registered in the ADAPAR repository, Bold® which has systemic, contact and ingestion classes of control, composed of acetamiprid (neonicotinoid) and fenpropathrin (pyrethroid), and Maxsan® which has similar classes of control, however, composed of dinotefuran (neonicotinoid) and pyriproxyfen (pyridyloxy propyl ether) (ADAPAR, 2021).

The common bean grain value was composed from the average 60 kg common bean carioca type 1 prices during the months of each crop season (Table 2). This data was obtained from monthly price ranges in the northern Paraná State region, collected by the state's Sistema de Informação do Mercado Agricola [SIMA] (2021). The grain value of each treatment was then calculated using their respective yields and the average common bean 60kg value during their respective seasons, 2019 and 2020/21.

Table 2
Average 60 kg carioca type 1 common bean value, in Brazilian Real, in the Paraná State during the summer season of 2018/2019 and rainy season of 2020/2021

Season	Month / Year	Value (R$ 60kg^{-1})	Average (R$ 60 kg^{-1})
Summer season 2019	January / 2019	201.42	259.27
	February / 2019	317.02	
	March / 2019	293.93	
	April / 2019	224.72	
Rainy season 2020/2021	October / 2020	260.42	274.83
	November / 2020	277.04	
	December / 2020	296.27	
	January / 2021	265.60	

The economic injury level (EIL) was calculated using a linear regression plot composed of the production reduction values (PR) as the ordinate, and the *E. heros* population density per meter as the abscissa. The EIL is the value where the calculated regression line equals the previously calculated damage tolerance percentage (D %), represented in *E. heros* population density per meter.

The EIL was adjusted using decreasing spraying efficiency values. Since, an efficiency of at least 80% control is obliged by law (Knabben & Costa, 2012; MAPA, 2019).

The Economic Threshold (ET) was considered 90 % of the original EIL, given the cultivars characteristics of early cycle and determinate growth habit, which offer a smaller window of control, when compared to medium cycle and inderterminate growth habit common bean cultivars.

Results and Discussion

In both seasons *Euschistus heros* had no significant effect over the common bean grained pod production, independent of the population density (Table 3). In the first harvest, the summer season of 2019, an average of 121 grained pods per treatment was harvested. During the rainy season of 2020/21, the average amount of grained pods produced was greater than the first harvest in 2019, in average 280 grained pods per replicate (Table 3). Panizzi and Slansky (1985) found that brown stink bugs also had no effect on soybean pod and grain production, only a direct effect over the damaged and aborted grain quantities. *Euschistus heros* nymphs' feeding, starting at the second instar and beyond, caused damage and significant grain staining to soybean grains during the full bean growth stage (R6), however, no grain weight variations were evaluated (Tessmer et al., 2022). Pastorio Oliveira et al. (2022), found that two *E. heros* per soybean plant, on either resistant or susceptible cultivars, resulted in no significant difference towards total damaged grain weight, the same occurred when comparing the same cultivars but with four stink bugs per plant, yet the damaged grain weight escalated in relation to the increase in insect density.

Table 3
Average (± SD) grained pods, flat pods and aborted grains in varied *Euschistus heros* population densities infesting the IPR Curió common bean cultivar during the summer season of 2019 and rainy season 2020/2021

E. heros population density (m^{-1})	Summer season 2019			Rainy season 2020/2021		
	Pods		Aborted grains	Pods		Aborted grains
	grained	flat		grained	flat	
0 (Witness)	105 ± 26	24 ± 5 c	38 ± 6 b	307 ± 66	11 ± 7	77 ± 10 c
1	141 ± 60	36 ± 29 c	64 ± 59 b	280 ± 66	17 ± 6	186 ± 41 a
2	115 ± 60	22 ± 9 c	33 ± 10 b	283 ± 46	16 ± 6	131 ± 17 b
3	122 ± 40	35 ± 17 c	61 ± 25 b	260 ± 22	19 ± 8	115 ± 49 b
4	139 ± 77	60 ± 18 b	98 ± 35 a	244 ± 26	17 ± 8	204 ± 18 a
5	104 ± 37	100 ± 4 a	152 ± 38 a	303 ± 28	14 ± 2	87 ± 15 c
C.V. (%)	40.59	36.08	48.96	14.46	43.56	18.52
p-value	**ns**	< 0.01	< 0.01	**ns**	**ns**	< 0.01

Averages (± SD) followed by the same letter in the columns do not significantly differ, Scott-Knott test ($\alpha \leq 0,05$).
ns Not significant.

A significant increase in flat pods as the *E. heros* density rose was only observed during the summer season (p-value < 0.01). The rainy season's favorable crop conditions may have been an important factor towards pod conservation, instead of pod abortion, given the greater abundance of available water, milder temperatures and resulting plant response towards insect feeding (Meyer et al., 2014). Soybean grown in greenhouse conditions, while infested with *E. heros,* had no significant change in grained or flat pod production (Nunes & Corrêa-Ferreira, 2002). This may demonstrate that in more favorable and controlled growing conditions, leguminous plants could tolerate greater *E. heros* damage and result in fewer pod abortions. The study by Vyavhare et al. (2015), demonstrated that the stink bug *Piezodorus guildinii* (Hemiptera: Pentatomidae) caused a significant increase in flat soybean pods, this highlights the contrast in the difference between these Pentatomidae species' damage and crop degradation potential.

During both seasons the number of aborted grains rose congruently with the stink bug density, but the number of aborted grains was greater during the rainy season, as was the number of grained pods. So, the greater number of pods produced during the rainy season inevitably resulted in a greater number of aborted grains, however, not primarily due to the varied *E. heros* densities, given that pod abortion is a common bean natural behavior, possibly to accommodate fruit set, and the variation between seasons was probably due to greater flower production and consequent pod production during the rainy season (Table 3) (Osumi et al., 1998; Peksen, 2007). In the summer season the amount of flat pods increased starting at a population density of four *E. heros* per meter, with an average of 60, reaching a significantly higher average of 100 flat pods in the five *E. heros* per meter density. However, the treatments with fewer than four brown stink bugs per meter had no significant difference in flat pod production, including the witness (p-value < 0.01). The average aborted grain amount was not different between the witness and the treatments up to three stink bugs per meter (p-value < 0.01). However, both the four and five *E. heros* treatments shared the greatest amounts of aborted grains, in average 98 and 152 respectively, with no significant difference between them. In summary, the grained pod production was not significantly affected by increasing *E. heros* population densities, yet, higher densities, above three *E. heros* per meter, significantly increase flat pods and aborted seeds (Table 3). The lack of *E. heros* feeding influence over this common bean cultivar's grained pod production, in both seasons, agrees with Nunes and Corrêa-Ferreira (2002), yet contrasts in the fact that the authors' studied soybeans did not demonstrate an increase in flat pods, indicating a possible susceptibility and abortion of common bean pods, given *E. heros* herbivorous feeding.

Congruent to the summer season, the average amount of grained pods was not significantly affected by the varying *E. heros* density treatments during the rainy season, composed of in average 244 for the density of four *E. heros* up to 307 grained pods for the witness. The sum of flat pods was not significantly affected by the different treatments, ranging from in average 11 for the witness and 19 flat pods for the density of three stink bugs. There was a significant increase in aborted grains, when compared to the witness, the greatest amounts resulting from both one and four stink bugs per meter, in average 186 and 204 aborted grains respectively ($p < 0.01$). Five stink bugs per meter did not significantly differ from the witness treatment, both resulting in the fewest number of aborted grains, in average 87 and 77 respectively (Table 3).

The average mass of damaged grain produced during both seasons was significantly affected by the increasing *E. heros* population densities, with an average weight of 406 kg ha^{-1} for the density of one stink bug and 924 kg ha^{-1} for the density of five. However, a greater total grain mass was produced during the rainy season in comparison to the summer season (Table 4). In the summer season a significant reduction in healthy grain mass was observed with increasing *E. heros* densities when compared to the witness, which produced an average mass of 1,700 kg ha^{-1}. However, there was no significant decrease in healthy grain mass when above two stink bugs per meter, with an average mass of 909 kg ha^{-1} (p-value < 0.01). The mass of damaged grains jointly increased with the rising *E. heros* densities per meter, and five stink bugs resulted in the significantly greatest average mass of 1,028 kg ha^{-1} (p-value < 0.01) (Table 4). Yet, between the treatments, the total grain mass was not significantly different, thus, *E. heros* was not able to significantly reduce the IPR Curió cultivar's total grain production during the summer season, which average mass varied between 1700 kg ha^{-1} for the witness and 1607 kg ha^{-1} for the density of five *E. heros* (Table 4).

In the rainy season assay of 2020/21, an average healthy grain mass of 3563 kg ha^{-1} was harvested from the witness treatment. The treatments' healthy grain mass did not significantly vary from the witness. The damaged grain mass varied significantly between the treatments and the witness, the lightest average mass of 406 kg ha^{-1} was from one *E. heros* per meter, and the remaining densities resulted in double that mass, however, no significant difference was found between them, with five stink bugs resulting in an average of 924 kg ha^{-1} of damaged grains (p-value < 0.01). The total grain production mass was not affected by the increasing *E. heros* densities, with an average total grain production of 3563 kg ha^{-1} from the witness. The average rainy season total grain mass was more than twice as heavy as the summer season's harvest, with a greater healthy grain output despite the *E. heros* increasing densities (Table 4).

The increase in total damaged grains significantly degrades its market value, since common bean grain is basically sold in natura in Brazil and influenced by the consumer's visual reception (Silochi et al., 2021). The greater quantity of damaged grains also decreases the grain's quality during classification in Brazil, where the common bean type 1 classification has only a 2.5% tolerance of dark or damaged grains (Knabben & Costa, 2012). Considering a 2.5% tolerance, during the summer season the density of one stink bug per meter resulted in a damaged grains average mass of 265 kg ha^{-1}, which equates to about 19% of the average total grain mass produced (1422 kg ha^{-1}), and during the rainy season, one stink bug per meter resulted in a damaged grain average mass of 406 kg ha^{-1}, which amounts to about 11% of the average total grain mass (3569 kg ha^{-1}) (Table 4). Thus, in both harvests a density of one stink bug per meter was already capable of considerable classification devaluation.

Table 4
Average (± SD) healthy, damaged and total grain mass in varied *Euschistus heros* population densities infesting the IPR Curió common bean cultivar during the summer season of 2019 and rainy season 2020/2021

E. heros population density (m^{-1})	Summer season 2019			Rainy season 2020/2021		
	Healthy grains	Damaged grains	Total grains	Healthy grains	Damaged grains	Total grains
	- - - - - - - - - - - kg ha^{-1} - - - - - - - - - -			- - - - - - - - - - - kg ha^{-1} - - - - - - - - - -		
0 (Witness)	1700 ± 388 a	0 ± 0 d	1700 ± 388	3563 ± 1364	0 ± 0 c	3563 ± 1364
1	1157 ± 322 b	265 ± 47 c	1422 ± 355	3162 ± 1103	406 ± 123 b	3569 ± 1161
2	909 ± 224 c	449 ± 114 b	1358 ± 288	1993 ± 714	943 ± 193 a	2936 ± 787
3	713 ± 69 c	622 ± 115 b	1335 ± 62	2331 ± 587	883 ± 112 a	3214 ± 631
4	607 ± 524 c	560 ± 151 b	1167 ± 399	2008 ± 822	788 ± 148 a	2796 ± 698
5	579 ± 136 c	1028 ± 147 a	1607 ± 172	2629 ± 288	924 ± 120 a	3553 ± 365
C.V. (%)	34.49	19.84	21.32	35.13	19.92	28.21
p-value	< 0.01	< 0.01	ns	ns	< 0,01	ns

Averages (± SD) followed by the same letter in the columns do not significantly differ, Scott-Knott test (α ≤ 0,05).
ns Not significant.

However, the visual and nutritional quality reduction potential of *E. heros,* feeding on leguminous grains, should be highlighted (Vieira, 1983; Panizzi & Slansky, 1985; Corrêa-Ferreira & Azevedo, 2002). Especially, since the brown stink bug may facilitate the transmission of yeast-spot [*Eremothecium coryli* (Peglion & Kurtzman) syn. *Nematospora coryli* Peglion & Kurtzaman] (Saccharomycetales: Eremotheciaceae), which greatly degrades grain value during classification (Paradela et al., 1972; Quintela, 2009; Barbosa et al., 2021).

Owens et al. (2013) found that soybean cultivated during the summer season and infested with different *Halyomorpha halys* (Hemiptera: Pentatomidae) densities produced a significantly greater mass of damaged grains as the densities rose, however, the total grain mass was not affected. A finding which concurs with the present study's results, demonstrating the similar reactions of these leguminous plants and both stink bug species' damage potentials. The plant reproductive stage in which *Euschistus heros* infests may influence the total damaged grain mass output, since *E. heros* which were infested on soybean pods during the beginning seed stage (R5), resulted in a greater mass of damaged grains, but when the soybean pods were infested during the maturing stage (R7), very few damaged grains were harvested, this could prove that an early (R5-6) neotropical brown stink bug infestation results in greater losses compared to a tardy infestation (R7) (Panizzi et al., 2000). During both seasons, the IPR-Curió plants were infested while in full flowering (R2), thus the damage potential contemplated every grain stage of the common bean's reproductive stage, mimicking field conditions and insect behavior, where *E. heros* potentially damaging populations tend to peak at grain development stages (Borges et al., 2011). As shown during this and other studies , it is assumed that the neotropical brown stink bug does not significantly affect the total grain yield of soybean and common bean (Owens et al., 2013; Panizzi et al., 2000; Nunes & Corrêa-Ferreira, 2002).

The Economic Injury Level (EIL) was calculated considering the common bean carioca type 1 value for the summer and rainy seasons, tallied at 259.27 and 274.83 R$ 60kg^{-1} (Brazilian real per 60 kilograms) respectively, the treatment cost composed from the sum of the operational cost, 1078.12 R$ ha^{-1} (Brazilian Real per hectare) in the summer and 1085.68 R$ ha^{-1} in the rainy season, with each of the insecticides' cost , and finally adjusted to each season's witness total grain mass averages of 1700 kg ha^{-1} during the summer and 3563 kg ha^{-1} during the rainy season (Table 1, 2 & 5). The production reduction (PR) was obtained from the direct comparison, in percentage, between each of the damaged grain masses and the witness' healthy grain mass for each season (Table 5). During the summer season one *E. heros* per meter resulted in a reduction of roughly 16%, yet for the rainy season, given the same population density, only an 11% reduction was observed (Table 5). The production reduction (PR) (PR = ordinate) was then implemented in a linear regression analysis with the varying *E. heros* population densities (abscissa) (Figure 2A and Figure 2B). The Economic Injury Level (EIL) was found using the linear regression equation, which was at the calculated damage tolerance percentage (D %), of 15.8%, represented as the *E. heros* density of 1.42 brown stink bugs per meter (R^2 = 0.97) in the summer season (Figure 2A). The linear regression demonstrates the destructive potential of increasing *E. heros* populations to an early cycle carioca type common bean during the summer season. The linear regression formula demonstrated that each *E. heros* per linear meter was responsible for an 11% reduction in the final healthy grain yield. The treatment with four stink bugs per meter resulted in a lower PR than the treatments with three and five stink bugs per meter, 33, 37 and 60%, respectively (Table 5).

Similar to the summer season, during the rainy season (2020/21) EIL, D % and PR values were calculated using the respective season's yield, common bean carioca type 1 market value and treatment cost (sum of operational and insecticide costs) (Table 5). Two new insecticides were registered and thus used during this season (ADAPAR, 2021). The D % was calculated for the different insecticides' market value. However, the D % showed only a small difference between the varying chemicals, 6.88% for Bold®, 7.02% for Fastac Duo®, and 6.93% for Maxsan®, the EIL for each chemical also demonstrated a small variation of 1.06, 1.08 and 1.07 *E. heros* per meter, respectively. During the rainy season of 2020/21, the linear regression formula demonstrated that each *E. heros* per meter was capable of reducing 6% of the final healthy grain yield (Figure 2B). The four *E. heros* density resulted in a PR of 22%, greater only than the treatment with one *E. heros* per meter which resulted in an 11% reduction (Table 5). The highest PR was observed for both two and five stink bugs per meter, a production reduction of 26%.

Table 5
Production reduction rate (PR), damage tolerance percentage (D %) and economic injury level (EIL) for IPR Curió common bean cultivar infested with varied *Euschistus heros* population densities during the summer season of 2019 and rainy season 2020/2021

Season	*E. heros* population density (m^{-1})	Yield (kg ha^{-1})	PR (%)	Insecticide	D %	EIL (*E. heros* m^{-1})
Summer 2019	0 (Witness)	1700 *	0	Fastac Duo®	15.8 ***	1.42***
	1	265 **	16			
	2	449 **	26			
	3	622 **	37			
	4	560 **	33			
	5	1028 **	60			
Rainy 2020/2021	0 (Witness)	3563 *	0	Bold®	6.88****	1.06****
	1	406 **	11			
	2	943 **	26	Fastac Duo®	7.02****	1.08****
	3	883 **	25			
	4	788 **	22	Maxsan®	6.93****	1.07****
	5	924 **	26			

* Average witness healthy grain mass. ** Average damaged grain mass.
*** Calculated with the sum of the operational cost (1078.12) in R$ ha^{-1}, insecticide Fastac Duo® (83.00) value in R$ ha^{-1} and common bean type 1 average market value during the summer season 2019 (R$ ha^{-1}).
**** Calculated with the sum of the operational cost (1085.68) in R$ ha^{-1}, the specific insecticide market values in R$ ha^{-1} and common bean type 1 average market value during the rainy season 2020/2021 (R$ ha^{-1}).

The calculated damage tolerance percentage (D %) and economic injury level (EIL) varied between the seasons, during the summer season, 15.8% and 1.42 *E. heros* per meter respectively, and in the rainy season, 6.95% and 1.07 *E. heros* per meter, respectively (Figure 1A and 1B). This difference is due to the different common bean (60 kg) prices (Table 1), spraying costs (Tables 1), and the witness yields (Table 4). The different insecticide prices did not significantly affect the D % and EIL for *E. heros* infesting the IPR Curió cultivar Quintela (2001), determined the economic threshold (ET) for stink bugs, in general, for common bean, with the cultivar Pérola, an indeterminate growth type bean, with a secure margin, as two big stink bugs per beat cloth during sampling. The IPR Curió is a determinate growth type early cycle cultivar, and in both assays the EIL was bellow two *E. heros,* given that during the summer season, a density of two stink bugs per meter could result in a damaged grain mass of 449 kg ha^{-1}, almost eight sixty-kilogram sacks per hectare, and during the rainy season, 943 kg ha^{-1}, approximately 16 sixty-kilogram sacks per hectare. For soybean the ET for *E. heros* is two per meter during grain production and one per meter during seed production (Corrêa-Ferreira & Panizzi, 1999). These ET values have been used in Brazil for common bean production as well (Barbosa et al., 2021). However, with the development of new cultivar technologies, like different cycle lengths and growth types, the fluctuating grain market values, and insecticides' prices, warrant continuous D %, EIL and ET studies striving to maintain ecologically and economically viable integrated pest management programs. An important emphasis is that the production reduction (PR) values described during both seasons, one brown stink bug per meter during the first season reduced 11%, and during the second season reduced 6%, highlighting the importance of constant pest monitoring, using beat cloth, pheromone baits and trap-cropping, given that the potential damage varies per season (Corrêa-Ferreira et al., 2013; Borges et al., 2011).

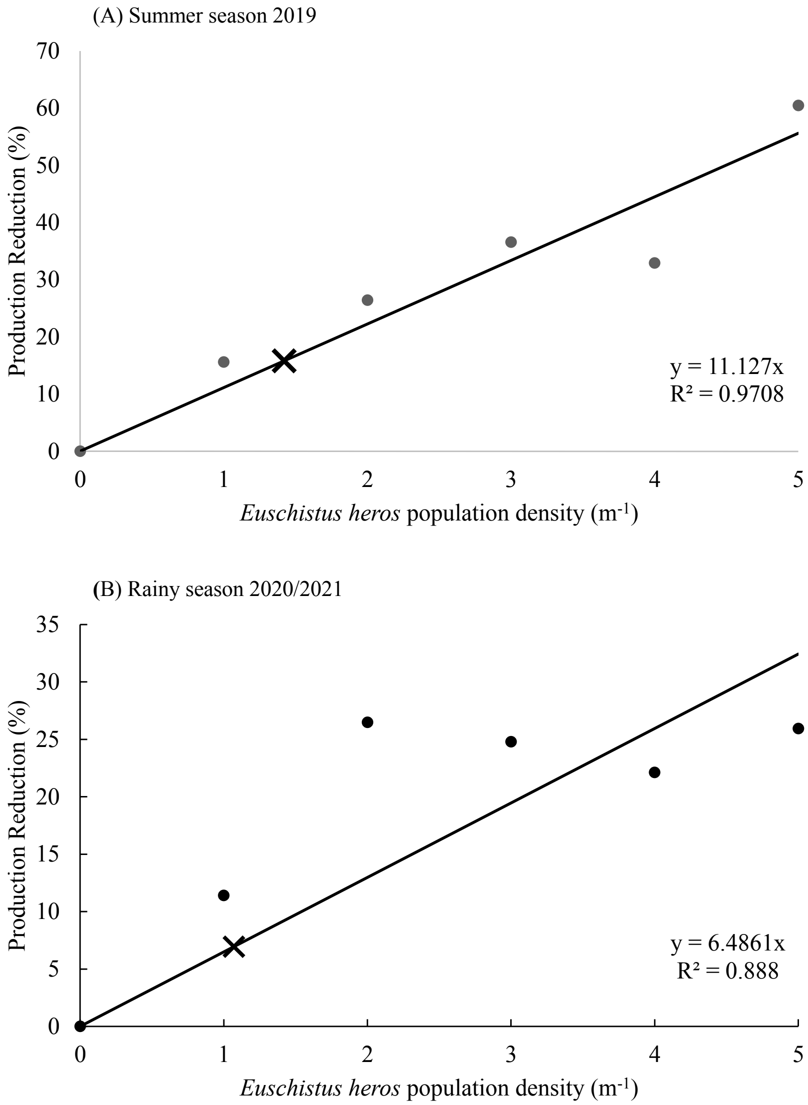

Figure 2. Production reduction of the IPR Curió cultivar infested with increasing *Euschistus heros* population densities during the summer season of 2019 (A) and rainy season 2020/2021 (B). Note: The "X" represents the damage tolerance percentage (D %) (abscissa) and congruently the economic injury level (*E. heros* m^{-1}) (coordinate): A) Summer season of 2019 "X" is 15.8 and 1.42, respectively, and the B) Rainy season 2020/2021 "X" is 6.95 and 1.07, respectively.

The economic threshold (ET) determination is based on an estimation of the moment of control, however, instead of being represented in a time scale, it is commonly represented in a population density value per determined area (example: pest per meter) (Pedigo et al., 1986). During the summer season (2019), with a spraying efficiency of 100 %, the ET is represented at 1.28 *E. heros* m^{-1}, representing 90 % of the previously calculated economic injury level (EIL) of 1.42 *E. heros* m^{-1}, but at a closer to field condition efficiency of between 80-70%, that value is raised to 1.60 and 1.83 *E. heros* per meter, respectively (Table 6). Thus, the assumed economic ET for the summer season was rounded to 1.50 *E. heros* m^{-1}, considering an 80 % spraying efficiency. For the rainy season (2020/21), a spraying efficiency of 100% would result in a ET of 0.96 *E. heros* m^{-1}, however in a field condition scenario of spraying efficiency (between 80-70%) that value is raised to 1.2 and 1.37 *E. heros* per meter respectively. Thus, the determined ET for IPR Curió during the rainy season was rounded to 1.00 *E. heros* m^{-1}, considering an 80 % spraying efficiency. The spraying efficiency evaluation demonstrated that in field conditions, where many other factors impact the potential efficiency, the decrease in the efficiency value increases the ET for *Euschistus heros* infesting early cycle common bean (Hilz & Vermeer, 2013). Thus, the pest management is postponed until the given density is reached, this is important to thwart re-spraying scenarios, which undermine the integrated pest management program's efficiency.

Table 6
Spraying efficiency correction for damage tolerance percentage (D %) and economic threshold (ET) in the IPR Curió common bean cultivar infested with varied *Euschistus heros* population densities during the summer season of 2019 and rainy season of 2020/2021

Spraying efficiency	Summer 2019		Rainy 2020/2021	
	D %	ET (*E. heros* m^{-1})	D %	ET (*E. heros* m^{-1})
1	15.8	1.28	6.95	0.96
0.9		1.42		1.07
0.8		1.6 *		1.2 *
0.7		1.83		1.37

* Established Economic Threshold.

Conclusions

Varied *E. heros* densities did not affect the total number of grained pods output for the IPR Curió cultivar. However, during the summer season, densities greater than three stink bugs per meter increased flat pod output and reduced healthy grain mass output, doubling damaged grain mass compared to a single *E. heros* per meter. During the rainy season, *E. heros* infestation led to more aborted grains. A single stink bug per meter reduced the healthy grain mass output by up to 11% in the summer and 6% in the rainy season. The economic threshold is 1.50 *E. heros* per meter during the summer season and 1.00 *E. heros* per meter during the rainy season.

Acknowledgements

Thanks are due to the Instituto de Desenvolvimento Rural do Paraná - IAPAR-EMATER (IDR-Paraná) for the infrastructure, the experimental area and support during the experiments, also to the Universidade Estadual de Londrina (UEL) for the support and guidance. Thanks to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the fellowships granted to the students participating in this study.

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