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Diagrammatic scale to quantify the damage caused by bean thrips to the peanut crop

Abstract – The objective of this work was to develop and validate a diagrammatic logarithmic scale to evaluate the damage caused by the *Caliothrips phaseoli* bean thrips to peanut (*Arachis hypogaea*). Leaflets of artificially infected peanut plants were collected, and the damaged leaf area (DLA) was calculated using the SisCob software. Six-, seven-, eight-, and nine-class scales were developed, and the range of each class was obtained with the 2-LOG software. The leaflets were analyzed by 12 raters using the four proposed scales. The scales were validated as to: precision and accuracy, using the linear regression between the DLA and estimated area; and reproducibility, by the linear regression between the estimations of the raters combined in pairs. The eight-class scale shows the best results in terms of accuracy and precision, as well as a high reproducibility.

Index terms: *Caliothrips phaseoli*, injury, leaflet area, pests, visual estimation.

Escala diagramática para quantificar danos causados por tripes do feijoeiro à cultura do amendoim

Resumo – O objetivo deste trabalho foi desenvolver e validar uma escala logarítmica diagramática para avaliar os danos causados pelo tripes do feijoeiro, *Caliothrips phaseoli*, em amendoim (*Arachis hypogaea*). Folíolos de plantas de amendoim infectadas artificialmente foram coletados, e a área foliar danificada (DLA) foi calculada com uso do programa SisCob. Foram desenvolvidas escalas com seis, sete, oito e nove classes, e a amplitude de cada classe foi obtida com o programa 2-LOG. Os folíolos foram analisados por 12 avaliadores com uso das quatro escalas propostas. As escalas foram validadas quanto à: precisão e acurácia, por meio da regressão linear entre a DLA e a área estimada; e reprodutibilidade, pela regressão linear entre as estimativas dos avaliadores combinadas em pares. A escala de oito classes apresenta os melhores resultados em termos de acurácia e precisão, bem como alta reprodutibilidade.

Termos para indexação: *Caliothrips phaseoli*, injúria, área foliar, pragas, estimativa visual.

Ana Cecilia Crenna[1 ✉],
Claudio Oddino[1],
Damián Francisco Giordano[1],
Jorge Antonio Giuggia[1] and
Diego Giovanini[1]

[1] Universidad Nacional de Río Cuarto, Facultad de Agronomía y Veterinaria, Ruta Nacional 36, Km 601, Código Postal 5800, X5804BYA Río Cuarto, Córdoba, Argentina.
E-mail: ccrenna@ayv.unrc.edu.ar, coddino@ayv.unrc.edu.ar, dgiordano@exa.unrc.edu.ar, jgiuggia@ayv.unrc.edu.ar, dgiovanini@ayv.unrc.edu.ar

✉ Corresponding author

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Introduction

Argentina is one of the main producers of peanut (*Arachis hypogaea* L.) worldwide, playing an important role in the international market in terms of price formation, high volumes of exportable products, and recognized quality of the commercial product (Benencia & Fernandez, 2017).

The peanut (*Arachis hypogaea* L.) crop is known to be attacked by several arthropod pests, such as thrips that cause direct damage to the plants by sucking sap from the surface of their leaflets, on whose upper and lower parts, respectively, white and necrotic lesions appear (Gadad et al., 2014). Both nymphs and adults feed similarly, preferring areas protected from solar radiation (Gadad et al., 2014; Boito et al., 2017).

The *Caliothrips phaseoli* (Thysanoptera: Thripidae) bean thrips is the pest most commonly observed in the peanut crop in the central-southern province of Córdoba, Argentina (de Breuil et al., 2015; Boito et al., 2017).

The severity of the damage caused by thrips to the peanut crop is usually evaluated subjectively by analyzing visually the caused symptoms (Moraes, 2005; Montes et al., 2013). Therefore, developing and validating a diagrammatic scale is useful to determine disease and pest intensity, which is important for different purposes including understanding yield loss, comparing cultivar behavior, and evaluating the effects of chemical and biological control (Bock et al., 2010; Boito et al., 2013; Vieira et al., 2014; Crenna et al., 2021). Moreover, the diagrammatic scales used to evaluate the damage caused by pests provide exact, accurate, and reproducible results both by experienced and inexperienced raters (Boito et al., 2013; Crenna et al., 2021; Juventia et al., 2021).

The objective of this work was to develop and validate a diagrammatic logarithmic scale to evaluate the damage caused by the *C. phaseoli* bean thrips to peanut.

Materials and Methods

Seeds of the Granoleico peanut cultivar were planted in pots in a greenhouse at Universidad Nacional de Río Cuarto, located in Córdoba, Argentina (64°17'54"W, 33°6'24"S, at 425 m of altitude). The climate of the region is Cwa according to Köppen-Geiger's classification. The used pots – with a 23 cm diameter and a 20 cm height – were washed and disinfected with 70% ethanol and 10% sodium hypochlorite and then filled with 4 kg of a soil:sand mixture (1:1), which was previously sterilized for 3 hours, at 180°C, during three consecutive days, using the TDSF/A60 analog forced-air circulation oven (Tecno Dalvo, Santa Fe, Argentina). Two days before sowing, each pot was watered until field capacity.

After sown, the plants were grown at 30/15°C day/night temperatures, at 60–70% relative humidity, and under a natural photoperiod, being watered as needed according to field capacity. Since the plants were monitored for insect or disease occurrence, insecticide or fungicide spraying was not necessary. In the R1 stage, the plants were artificially infested by placing leaflets attacked uniformly by *C. phaseoli* in all pots; the infested leaflets were collected from a peanut field located in the central-southern region of the province of Córdoba (63°52'23"W, 32°49'37"S). To cover the desired percentages of damage levels, leaflets were collected when a wide range of thrip damage was observed, characterized by white lesions on their upper surface (Gadad et al., 2014; Boito et al., 2017).

The collected leaflets were photographed with a digital camera and analyzed by the SisCob, version 1.0, software (Jorge et al., 2010), used to generate the graphical representation of each leaflet in order to measure the healthy and damaged areas. Image digitization allows a rapid processing of samples and improves the capacity of the raters to discriminate between the healthy and damaged areas of plants (Del Ponte et al., 2017).

Diagrammatic scales with six, seven, eight, and nine classes were elaborated using the graphical representation of the leaflets, selected to represent each of the classes (Yadav et al., 2013; González-Domínguez et al., 2014; Cristiane-Delmadi et al., 2018).

The upper and lower limits of the developed diagrammatic scales were established using the leaflets with the lowest and highest damage percentages, whereas the midpoint was obtained mathematically using the principles of the Weber-Fechner stimulus-response law applied by the 2.LOG, version 1.0, software for Windows (Mora Aguilera et al., 2000). This procedure ensures that visual acuity is inversely proportional to the logarithm of the stimulus, meaning that resolution capacity is lost at a higher severity of the disease (Osada-Velázquez & Mora Aguilera, 1997).

The photograph of each leaflet was evaluated using the four proposed scales and was assigned to a class by 12 raters – half were agronomists with experience

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in the use of scales and the other half were students without previous experience. The accuracy and precision of the visual estimations of each rater using the different scales were determined by the linear regression analysis, considering actual damage data as the independent variable and estimated damage data as the dependent variable, using the InfoStat statistical software (Di Rienzo et al., 2015).

The accuracy of the estimates of each rater was determined using the t-test applied to the intercept of regression line a to confirm the H0: a=0 hypothesis and to the slope of regression line b to confirm the H0: b=1 hypothesis, at 5% probability. Values of a different from 0 indicate constant deviations, and values of b different from 1 indicate systematic errors in the assessments.

The precision of the evaluations was estimated using the coefficient of determination (R^2) and the absolute error distribution (= estimated damage - actual damage) (Mora Aguilera et al., 2000). Reproducibility, which indicates if a scale can be efficiently used by other raters, was determined using the R^2 obtained from the linear regressions between the estimations of the damage caused by the bean thrips made by the different raters, combined in pairs, using the InfoStat statistical software (Di Rienzo et al., 2015).

Results and Discussion

The actual damage values ranged from 0 to 99.84% for the six-, seven-, eight-, and nine-class scales elaborated using the collected leaflets (Table 1).

The analysis of accuracy showed that the b value for the six-class scale was correctly estimated by nine of the raters, which accounts for 75% of the assessments performed (Table 2). A b value equal to 1 was obtained by seven raters using the seven- and nine-class scales and by ten raters using the eight-class scale, meaning that 58 and 83% of the evaluations were statistically significant. Cristiane-Delmadi et al. (2018) highlighted that the degree of subjectivity that conditions the use of diagrammatic scales, as well as of most of the methods applied to quantify the damage caused by pests and diseases, can be minimized by training the raters.

Mean precision, measured through the R^2, ranged from 0.74 to 0.85. According to Capucho et al. (2011)

Table 1. Lower limit, midpoint, and upper limit of each of the six, seven, eight, and nine classes of the scales used to estimate the damage caused by the *Caliothrips phaseoli* bean thrips to peanut (*Arachis hypogaea*) plants.

Scale	Class	Lower limit (%)	Midpoint (%)	Upper limit (%)	Scale	Class	Lower limit (%)	Midpoint (%)	Upper limit (%)
	0	0	0	0		0	0	0	0
	1	0	4.74	11.40		1	0	3.50	7.41
	2	11.40	24.95	46.21		2	7.41	15.00	28.03
6 classes	3	46.21	68.94	85.16	8 classes	3	28.03	46.21	65.46
	4	85.16	93.68	97.46		4	65.46	80.70	90.22
	5	97.46	98.84			5	90.22	95.31	97.82
						6	97.82	98.84	
	0	0				0		0	
	1	0	2.81	5.39		1		2.38	4.23
	2	5.39	10.10	18.12		2	4.23	7.41	12.65
	3	18.12	30.36	46.21		3	12.65	20.77	32.18
7 classes	4	46.21	62.86	76.93	9 classes	4	32.18	46.21	60.86
	5	76.93	86.79	92.83		5	60.86	73.79	83.59
	6	92.83	96.23	98.05		6	83.59	90.22	94.35
	7	98.05	98.84			7	94.35	96.80	98.20
						8	98.20	98.84	

and Crenna et al. (2021), values above 0.75 are appropriate to validate a scale in terms of precision.

The eight-class scale showed the best results for accuracy and precision: the b value ranged from 0.83 and 1.01, with an average of 0.95; and only 16% of the raters tended to make systematic errors, indicating a high accuracy. This result is in agreement with the values obtained in the validation of other scales developed for the evaluation of pests (Boito et al., 2013; Sousa et al., 2017; Crenna et al., 2021). In addition, the mean R^2 value was the highest for the eight-class scale, ranging from 0.70 to 0.96 and being above 0.80 for 83% of the assessments, a result that confers a high precision to the estimation of foliar damage. Values above 80% are considered excellent in scales considered of high precision (Capucho et al., 2011; Sousa et al., 2017).

In general, most diagrammatic scales have from five to eight classes (Yadav et al., 2013; González-Domínguez et al., 2014; Vieira et al., 2014; Cristiane-Delmadi et al., 2018). Campbell & Madden (1990) concluded that the number of classes should not be too low (fewer than four), because the resolution power would also be low, or too high (more than ten), because it would be difficult to select the most appropriate class. In the present study, the eight-class scale meets these requirements (Figure 1).

The precision of a scale can be estimated using absolute errors or residuals, determined as the difference between the damage estimated visually and actual damage. The observed residuals are randomly dispersed around the prediction line (Figure 2), showing a suitable fit of the model (Campbell & Madden, 1990). The highest dispersion of errors is concentrated at the range of 5%, a value taken into account in the validation of the diagrammatic scales used to evaluate the damage caused by pests and diseases (Capucho et al., 2011; Boito et al., 2013; Nascimento et al., 2020). According to Stonehouse (1994), the speed and standardization resulting from the use of these scales can offset the presence of some level of absolute error in the assessments.

The comparison of the estimations of the raters, in pairs, showed R^2 values ranging from 0.50 to 0.91 (Table 3). Furthermore, 77% of the crossed correlations between raters yielded R^2 values

Table 2. Coefficient of determination (R^2) and slope b of the linear regression between the actual damage caused by the *Caliothrips phaseoli* bean thrips to peanut (*Arachis hypogaea*) plants and that estimated by 12 raters using the six-, seven-, eight-, and nine-class scales.

Rater	Class scales							
	6		7		8		9	
	R^2	b	R^2	b	R^2	b	R^2	b
1	0.85	0.99	0.94	0.96(1)	0.88	0.94(1)	0.93	0.96
2	0.48	0.91	0.62	0.96	0.76	0.95	0.77	0.93(1)
3	0.82	0.82(1)	0.91	0.88(1)	0.81	0.83	0.89	0.86(1)
4	0.75	0.96	0.66	0.94	0.81	0.98	0.69	0.95
5	0.66	0.96	0.81	0.99	0.87	0.99	0.85	1.00
6	0.69	0.97	0.74	0.98	0.88	1.01	0.78	0.98
7	0.83	0.90(1)	0.74	0.95	0.85	0.95	0.84	0.96
8	0.89	0.99	0.94	0.92(1)	0.96	0.99	0.94	0.94(1)
9	0.79	0.95	0.87	0.99	0.80	0.98	0.87	1.01
10	0.40	0.82(1)	0.64	0.90(1)	0.70	0.86(1)	0.59	0.89(1)
11	0.91	1.02	0.94	0.95(1)	0.94	0.98	0.95	0.97(1)
12	0.77	1.01	0.93	0.99	0.90	0.97	0.87	0.98
Mean	0.74	0.94	0.81	0.95	0.85	0.95	0.83	0.95

(1)Situations in which the null hypothesis (H_0: a=0 or H_0: b=1) was rejected by the t-test, at 5% probability.

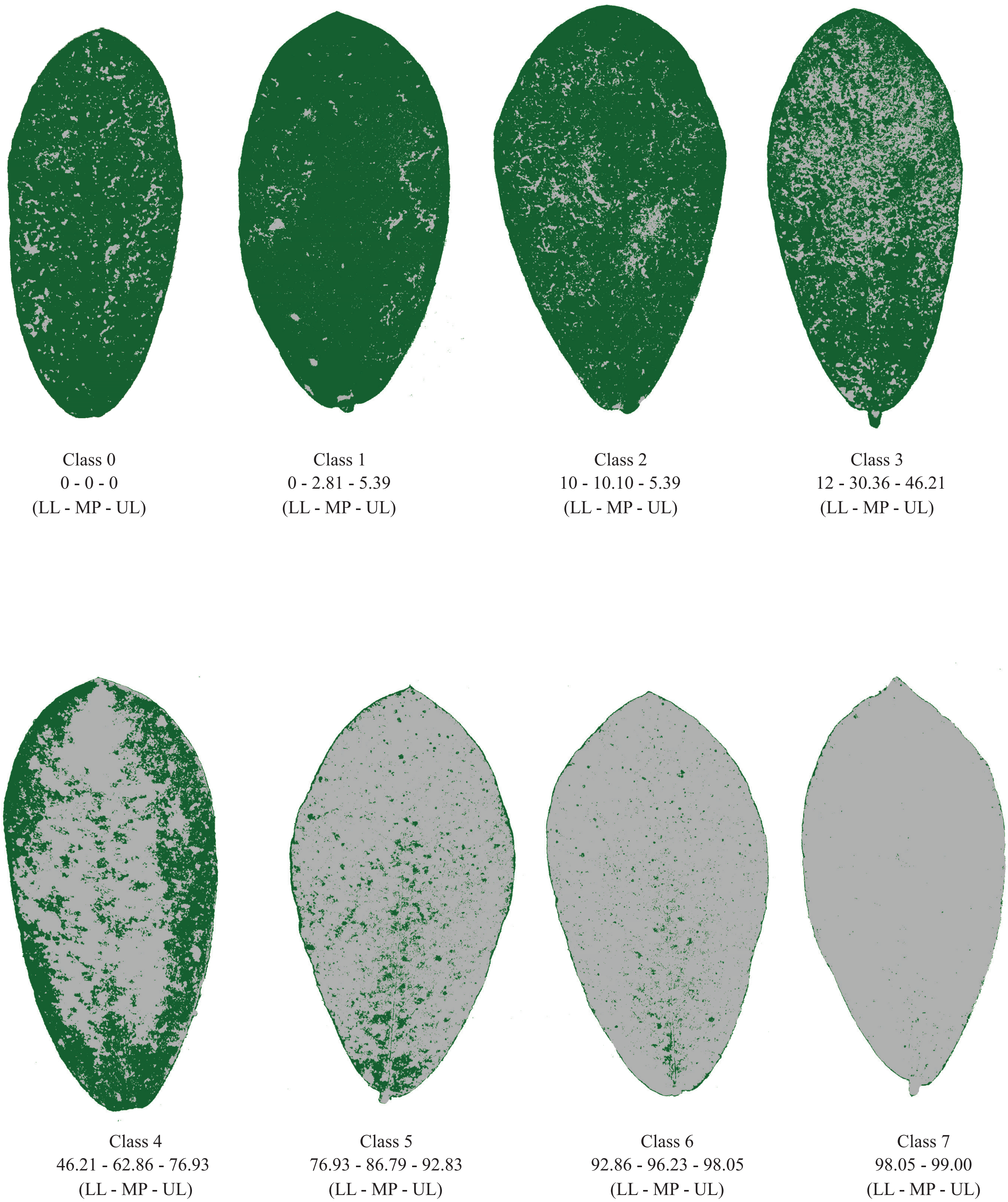

Figure 1. Eight-class diagrammatic scale of the damage caused by the *Caliothrips phaseoli* bean thrips to peanut (*Arachis hypogaea*) plants, elaborated using the graphical representations generated by the SisCob software (Jorge et al., 2010). For each class, the lower limit (LL), the midpoint (MP), and the upper limit (UL) are indicated.

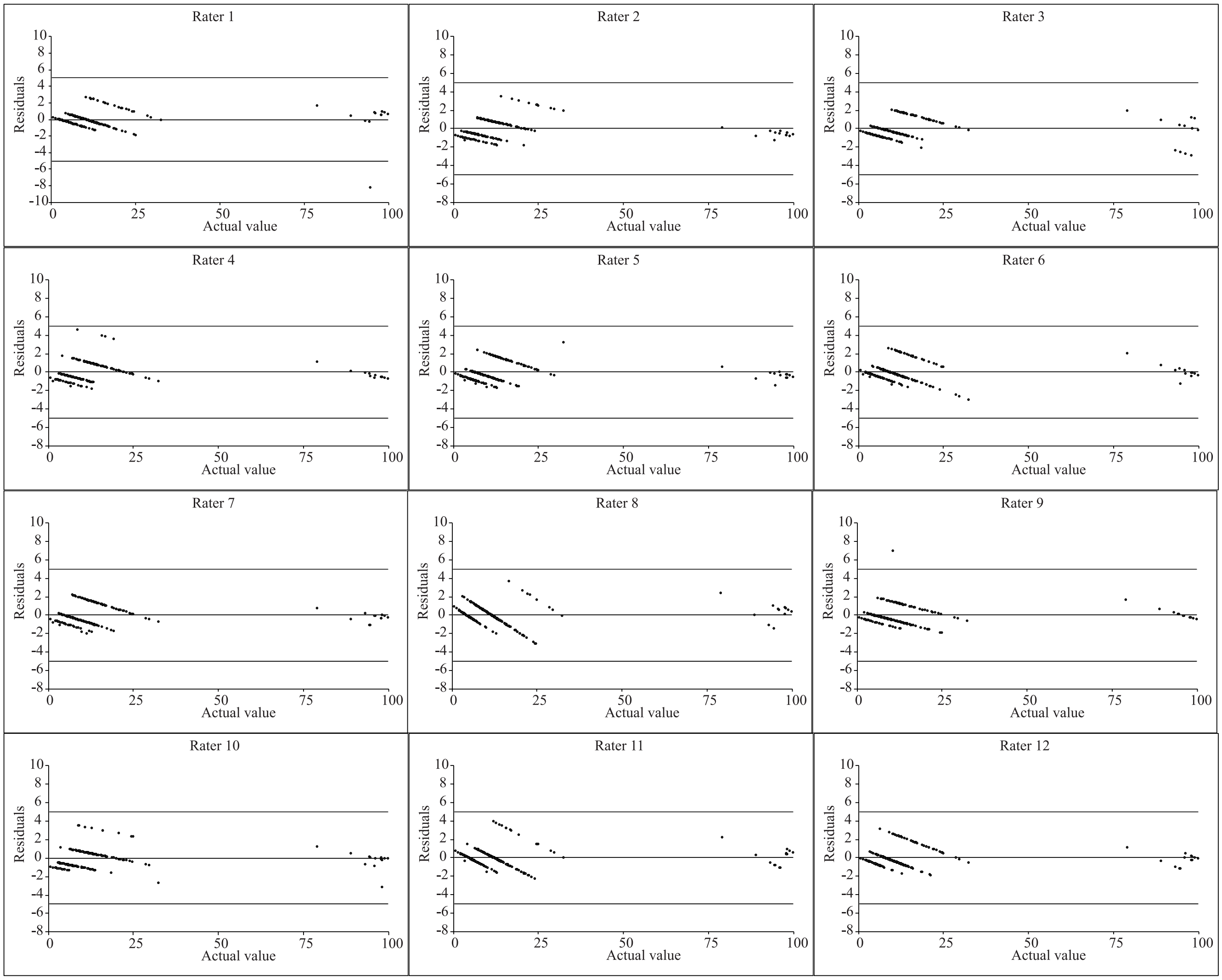

Figure 2. Distribution of residuals (estimated damage - actual damage) for the 12 raters as a function of the actual damage caused by the *Caliothrips phaseoli* bean thrips to peanut (*Arachis hypogaea*) plants, obtained using the eight-class scale.

Table 3. Coefficient of determination (R^2) obtained from the linear regression analysis between the estimations of 12 raters, combined in pairs, for the damage caused by the *Caliothrips phaseoli* bean thrips to peanut (*Arachis hypogaea*) plants.

Rater	2	3	4	5	6	7	8	9	10	11	12
1	0.69	0.78	0.74	0.82	0.80	0.81	0.86	0.74	0.58	0.85	0.81
2		0.72	0.71	0.74	0.70	0.72	0.71	0.64	0.57	0.75	0.76
3			0.78	0.81	0.81	0.77	0.76	0.69	0.63	0.81	0.80
4				0.81	0.78	0.78	0.76	0.71	0.60	0.80	0.76
5					0.80	0.83	0.82	0.75	0.62	0.83	0.81
6						0.77	0.85	0.78	0.67	0.89	0.86
7							0.81	0.69	0.65	0.82	0.80
8								0.78	0.68	0.91	0.87
9									0.50	0.81	0.76
10										0.65	0.67
11											0.88

above 70%, confirming the reproducibility of the estimations using the eight-class diagrammatic logarithmic scale. This reproducibility is similar to that found by several authors in the validation of diagrammatic scales (Capucho et al., 2011; Boito et al., 2013; Yadav et al., 2013; Crenna et al., 2021).

Conclusion

The eight-class diagrammatic scale developed for the estimation of the damage caused by the *Caliothrips phaseoli* bean thrips to peanut (*Arachis hypogaea*) plants is accurate and precise, presenting reproducible results.

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