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Research Article

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Susceptibility of different Malvaceae crops to herbivory induced by adult *Podagrica* spp.

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ABSTRACT

Podagrica uniforma Jacoby and *P. sjostedti* Jacoby are two important flea beetles that cause economic damage to several Malvaceae crops in Africa. Host preference by the beetles was evaluated under field conditions in 2017 and 2018 using fourty different crops in the family Malvaceae. The setup was a randomized complete block design with three blocks. Both *P. uniforma* and *P. sjostedti* highly preferred the okra genotypes, but the cotton genotypes were not damaged in both years. More than 80% of the crop leaves had beetle-induced buckshot(s) except for cotton (0%) and jute mallow (<55%). Leaf tissue removal exceeded 40% of the total leaf area of kenaf. Damages induced by the beetles disrupted plants' fitness, caused high leaf abscission and many crop stands were lost in both years. Only the okra fruits were damaged by the beetles, and plots with the Dwarf LP variety of okra recorded the highest crop loss (>43%) in both years. NHAe47-4, LD-88, and Dwarf LP okra genotypes were the first three Malvaceae crops that were most susceptible to *Podagrica* spp. attacks, while cotton genotypes were ranked as the least preferred crops. In conclusion, *P. uniforma* and *P. sjostedti* exhibited broad oligophagy in a polyculture of Malvaceae crops. While okra, kenaf, roselle, and jute mallow showed varying degrees of susceptibility to the beetles' attacks, the cotton genotypes appeared to be outside the host range. The potential of utilizing this beetle-Malvaceae interaction information in agroecosystems to minimize *Podagrica* spp. infestation and crop losses were discussed.

KEYWORDS: Crop damage, Flea beetles, Host preference, Malvaceae, *Podagrica*

INTRODUCTION

Malvaceae is a family of flowering plants (Angiosperm) with species comprising some of the world's most important food and fibre crops (Petruzzello, 2018). The major cultivated species in Africa include cotton (*Gossypium* spp.), kenaf (*Hibiscus cannabinus* L.), jute mallow (*Corchorus olitorius* L.), okra (*Abelmoschus esculentus* L. (Moench); *A. caillei* (A. Chev) Stevels), roselle (*Hibiscus sabdariffa* L.), baobab (*Adansonia* spp.), cacao (*Theobroma cacao*) and kola (*Cola acuminata* and *C. nitida*.). Depending on the crop type, the leaves, fruits, seeds, stem (fibre), flower, calyx, and roots have been subjected to a wide variety of food, therapeutic, aesthetic, and industrial uses (Hinsley, 2008; Ekoja *et al.*, 2022).

Flea beetles (*Podagrica* spp.) (Coleoptera: Chrysomelidae) have been reported to specialize in Malvaceae crops (Pitan & Adewole, 2011; Adesina *et al.*, 2014; Ekoja *et al.*, 2022), a relationship presumed to be a result of coevolution between the insects and this crop family (Futuyma *et al.*, 1983; Mitter *et al.*, 1991). In Africa, the species such as *P. puncticollis*, *P. uniforma*, *P. sjostedti*, *P. pallida*, *P. malvae*, *P. decolourata*, *P. submetallica*, *P. menetriesi*, and *Nisotra dilecta* have been reported to infest crops (Mohammed, 2000; Abebe *et al.*, 2021; Ekoja & Pitan, 2022). But in Nigeria, *P. uniforma* and *P. sjostedti* are the major species encountered in crop fields (Vanlommel *et al.*, 1996; Pitan & Ekoja, 2011, Ekoja & Pitan, 2022).

Several round feeding holes (buckshot) of approx. 1-2 mm^2 each on leaf lamina is one of the prominent damage symptoms associated with the beetle's presence on a susceptible host plant. This buckshot could lead to disruption of leaf chlorophyll content, induction of leaf loss, opportunistic infection by pathogenic organisms, reduction in plant's fitness, diminution of plant's dry matter yield, and plant death (Vanlommel *et al.*, 1996; Pitan & Ekoja, 2011; Ekoja *et al.*, 2012). On a host like okra, the beetles could establish up to 90% numerical dominance over other insect herbivores at the plant's vegetative growth stage (Odebiyi, 1980). Yield loss due to *Podagrica* spp. could be within the range of 54 - 70% of the total production per crop if control measures are not employed (Chaudhary & Dadheeck, 1989; Pitan & Ekoja, 2011).

Lots of research has suggested possible management tactics to curb field infestation by *Podagrica* spp. In many instances, frequent use of synthetic chemical insecticides has been recommended. But since the fresh leaves and fruits of most Malvaceae crops are consumed by man/livestock, it makes the adoption of such recommendations very delicate and dangerous. To achieve effective/judicious application of chemical or non-chemical insect pest management tactics, in-depth knowledge of the insect behavior (especially their preferred host and niche) and the relationship between varying population levels and crop loss is indispensable. In the long run, this information could also be helpful when developing crop varieties that are resistant to insect pest.

Presently, no crop in the Malvaceae family has been reported to be resistant to either *P. uniforma* or *P. sjostedti*, but research efforts have shown that the beetles demonstrate some degrees of preference for certain host plants within their host range (Pitan & Adewole, 2011). Phytophagous insects are known to possess numerous receptors that are stimulated by plant cues. Sensory inputs generated by the receptors are transmitted to the insect's central nervous system where they are processed, integrated, and interpreted as either positive or negative signals which facilitate their ability to make certain behavioural responses (Heard, 2000). Some studies have also shown that specialist herbivorous insects are guided by innate responses to certain cues emanating from plants during the process of host recognition and selection (Robert *et al.*, 2012; Coll Aráoz *et al.*, 2019). But information on Malvaceae hosts that elicit positive or negative responses by adult *P. uniforma* and *P. sjostedti* under field conditions is still scanty. Such information could also be helpful when developing an effective and sustainable pest management programme for the insect.

Oftentimes, crop producers are faced with the decision of selecting a crop or mixture of crops to cultivate, especially in areas with the recurring infestation of a particular pest. In such instances, the knowledge of the crop's susceptibility to key pests is crucial. But presently, studies on the susceptibility of different crops in the Malvaceae to *P. uniforma* and *P. sjostedti* herbivory are still scanty. For instance, Pitan and Adewole (2011) investigated the relationship between phytochemicals in some Malvaceae crops and host-preference by *P. sjostedti* at Abeokuta, Nigeria, but the study was limited to damage caused by one flea beetle species infesting a single variety of few cultivated Malvaceae crops. The study carried out by Abebe *et al.* (2021) only covered the susceptibility of different varieties of cotton to attacks by a different species of the beetle (*Podagrica puncticollis* Weise) in the hot tropical environment of Ethiopia. Therefore, the present study was carried out to evaluate the susceptibility of fourty different Malvaceae crops (specifically, genotypes of cotton, jute mallow, kenaf, okra, and roselle) to infestation and damage caused by adult *Podagrica* spp. under field conditions. The major parameters contributing to the variations in herbivory were also determined.

MATERIALS AND METHODS

Experimental Site

The study was out at the Organic Agriculture Skills Development Plots of the Federal University of Agriculture, Abeokuta, Nigeria (NG) (coordinates: Latitude 7°15'N, Longitude 3°25'E, 159 m above sea level, with a mean temperature of 29 ± 6ºC and mean relative humidity of 80 ± 7%) during the 2017 and 2018 cropping seasons. The site is located within the humid lowland rainforest region of Nigeria with two distinctive seasons [wet (March - October) and dry (November - February)].

Sources of Planting Materials

Fourty genotypes of Malvaceae crops *viz*: cotton, *Gossypium* spp. [(*1*) 10-Zamfara, (2) 37-Gusau, (3) 9-Maru Zamfara, (*4*) NG/SA/JAN/09/150, (*5*) MCt-11], kenaf, *H. cannabinus* [(*6*) NGB01215, (*7*) NGB01217, (8) NGB01216, (*9*) NGB01220, (*10*) NGB01212, (*11*) NGB01226, (*12*) NGB01221, (*13*) NGB01213, (*14*) NGB01222 and (*15*) NGB01214], roselle, *H. sabdariffa* [(*16*) MKD-Red-01, (*17*) NIHORT-Red, (*18*) Ashwe-Green-01, (*19*) NIHORT-Green, (*20*) NG/AO/11/08/006], jute mallow, *C. olitorius* [(*21*) NHGB/09/141, (22) NAC/NIH/040, (23) NG/SA/07/0207, (*24*) NG/OA/02/11/007, (*25*) NHGB/09/145)], okra, *A. esculentus* [(*26*) NGB01181, (27) NGB01190, (28) NGB01183, (29) NGB01184, (*30*) NGB01186, (*31*) NHAe47-4, (32) LD-88, (33) Clemson spineless, (*34*) Dwarf LP, (35) Dogo] and *A. caillei* [(36) NGB01197, (37) NGB01200, (38) NGB01202, (39) NGB01205, (*40*) NGB01204)] were evaluated. At least five genotypes with unique attributes were selected from each of the Malvaceae crop types. The seeds were obtained from the National Centre for Genetic Resources and Biotechnology (NACGRAB), Ibadan, NG, National Horticultural Institute (NIHORT), Ibadan NG, and Department of Crop and Environmental Protection, Federal University of Agriculture, Makurdi (FUAM), NG.

Experimental Procedure

Land clearing and cultivation (ridges) were done manually using a cutlass and hoe. The crops were laid out in a randomized complete block design with three blocks. The field comprised 120 plots (5 m × 4 m each) and 5 m buffer zones (uncultivated land with vegetation) separateing each block. A plot was made up of 4 ridges and the two middle rows make up the net plot. Three seeds were sown per hole and later thinned to one plant per stand at 10 days after sowing. Supplying of missing crop stands was carried out until 2 weeks after sowing to ensure a uniform number of plants per plot. A spacing of 60 cm × 45 cm was maintained in cotton plots, for kenaf, it was 15 cm × 15 cm, roselle was spaced at 50 cm × 75 cm, jute mallow was 15 cm × 30 cm, while the okra genotypes were sown using a recommended spacing of 60 cm × 40 cm. The crops were grown organic crop production field that was left to fallow for about 4 years. Chemical inputs such as fertilizers and insecticides were not used on the plots in both years. Weeding was done manually at 3, 6 and 8 WAS.

Data Collection

Field infestation by the beetles was natural in both years. Infestation and damage data were collected from plants ($n = 10$) tagged in the net plot. The abaxial and adaxial surfaces of the leaves were carefully examined at 9 WAS to count the number of *P. uniforma* and *P. sjostedti* per plant. Beetle counts were carried out between 06:00 and 10:00 Greenwich Mean Time (GMT) when the insects were relatively inactive. Data on the total number of leaves per plant and number of damaged leaves per plant were also taken to estimate the percentage of damaged leaves (%DL) per plant:

$$\%DL^{\phi} = \left(\frac{\text{Number of demaged fruits per plant}}{\text{Total number of fruits produed per plants}}\right)\times 100$$

$^{\phi}$ = a leaf was considered damaged when ≥1 buckshot(s) is/are found on the lamina.

The percentage of damaged fruits (%DF) per plant was derived from the quotient of the number of fruits with beetle-induced incisions on the skin and the total number of fruits produced per plant.

$$\%DF^{\delta} = \left(\frac{\text{Number of demaged fruits per plant}}{\text{Total number of fruits produed per plants}}\right)\times 100$$

$^{\delta}$ = a fruit was considered damaged when ≥1 incision(s) made by the beetles is/are found on the exocarp.

Furthermore, the total leaf area (cm^2) and leaf area consumed by the flea beetle (cm^2) were taken using a portable laser leaf area meter to estimate the percentage of leaf area damaged (%LAD) by the flea beetle damage:

$$\%LAD = \left(\frac{\text{Damaged leaf area}\left(\text{cm}^2\right)}{\text{Total leaf area}\left(\text{cm}^2\right)}\right)\times 100$$

The quotient of abscised leaves per plant and the total number of leaves produced per plant were used to estimate the percentage of leaf abscission per plant (%LAB).

$$\%LAB = \left(\frac{\text{Number of leaves abscised per plant}}{\text{Total Number of leaves produced per plants}}\right)\times 100$$

The difference between the initial stand count (i.e. stand counts after supplying and thinning operations at the beginning of the experiment) and the final stand count (at 12 WAS) was used to estimate the percentage loss stand (%LS) per plot.

$$\%LS = \left(\frac{\text{Initial stand count} - \text{Final stand count}}{\text{Initial stand count}}\right)\times 100$$

Statistical Analyses

Insect counts (c) were transformed using log (c + 1), while data in percentages were also transformed to arcsine values when needed to meet the assumptions of normality and homogeneity of variance. Numerical data were subjected to analysis of variance (ANOVA) using SAS Institute (2009). Where F-statistics for the ANOVA were significant, means were separated using Student Newman Keuls test ($\alpha = 0.05$). Actual means and standard error values are presented in the text and tables. Pearson's correlation between infestation and damage/crop loss data collected in both years was also carried out. The classical selection index (Smith, 1936) was used to rank the susceptibility of the tested Malvaceae crops based on the infestation and damage parameters measured.

RESULTS

Variations in the Number of Adult *Podagrica Uniforma* and *P. Sjostedti* on Different Malvaceae Crops

The crop genotypes tested and evaluated were all susceptible to *Podagrica* spp. infestation except for the cotton genotypes. All through the periods of assessment, none of the beetle species was found on the 37-Gusau and MCt-11 genotypes of cotton. At 9 WAS, most of the crops were flowering and this period appeared to be the peak of the beetles' infestation in the field as we observed a significant reduction in the number of flea beetles per plant after this period.

The number of the flea beetle per plant varied significantly (*P. uniforma*: $F = 23.31$; df = 39, 78; $P < 0.001$, *P. sjostedti*: $F = 20.18$; df = 39, 78; $P < 0.001$, Total: $F = 51.95$; df = 39, 78; $P < 0.001$) among the Malvaceae crops in 2017 (Table 1). Similar variation (*P. uniforma*: $F_{39, 78} = 21.12$; $P < 0.001$, *P. sjostedti*: $F = 43.41$; df = 39, 78; $P < 0.001$, Total: $F = 62.81$; df = 39, 78; $P < 0.001$) was observed in 2018 (Table 1B). Both *P. uniforma* and *P. sjostedti* demonstrated similar patterns in their host choice in the polyculture of Malvaceae crops. The order was mostly okra > roselle, > kenaf > Jute mallow > cotton. NHAe47-4 variety of okra recorded the highest number of flea beetles per plant, but it was not significantly different ($P > 0.05$) from the number observed on LD-88, Dwarf LP, NGB01183, NGB01186, NGB01190 and NGB01204 varieties of okra, and the number on NG/AO/11/08/006, MKD-Red-01, NIHORT-Red, Ashwe-Green-01, and NIHORT-Green genotypes of roselle in 2017. In 2018, NHAe47-4 and LD-88 varieties of okra hosted more flea beetles per plant than other crops, but the number was not significantly different ($P > 0.05$) from that of Clemson spineless, Dwarf LP varieties of okra, and the number on Ashwe-Green-01 and NIHORT-Green genotypes of roselle. Both *P. uniforma* and *P. sjostedti* seem to avoid the cotton genotypes throughout the experiment. Although we observed two *P. sjostedti* on the leaves of 10-Zamfara and 9-Maru Zamfara variety cotton at 9WAS, no damage was made to the leaf lamina and other parts of the crops.

Damage Induced by *Podagrica* spp. on Different Malvaceae Crops Under Field Condition

The successful host choice by both beetle species and their aggregation on the preferred niche(s) was in most cases followed by acceptance of the host and intense herbivory. The crop leaves were the most preferred site for feeding, mating and torpor.

Table 1: Number of *Podagrica* spp. per plant in Malvaceae crop field at Abeokuta, Nigeria

Genotypes	CT	2017			2018		
		P. uniforma	*P. sjostedti*	Total	*P. uniforma*	*P. sjostedti*	Total
10-Zamfara	Co	0.00±0.00 h	0.67±0.33 ijk	0.67±0.33 n	0.00±0.00 g	0.00±0.00 m	0.00±0.00 l
37-Gusau	Co	0.00±0.00 h	0.00±0.00 k	0.00±0.00 n	0.00±0.00 g	0.00±0.00 m	0.00±0.00 l
9-Maru Zamfara	Co	0.00±0.00 h	0.67±0.33 ijk	0.67±0.33 n	0.00±0.00 g	0.00±0.00 m	0.00±0.00 l
NG/SA/JAN/09/150	Co	0.00±0.00 h	0.00±0.00 k	0.00±0.00 n	0.00±0.00 g	0.00±0.00 m	0.00±0.00 l
MCt-11	Co	0.00±0.00 h	0.00±0.00 k	0.00±0.00 n	0.00±0.00 g	0.00±0.00 m	0.00±0.00 l
NGB01212	Ke	7.33±0.33 a-d	3.00±1.00 e-i	10.33±0.67 d-i	4.00±0.58 def	3.00±0.00 kl	7.33±0.58 jk
NGB01213	Ke	5.00±0.58 c-g	3.33±0.33 d-i	8.33±0.33 g-k	5.67±0.88 c-f	3.33±0.33 kl	9.00±0.58 ijk
NGB01214	Ke	5.67±0.33 a-f	3.00±0.58 e-i	8.67±0.33 f-j	4.00±0.58 def	4.67±1.20 h-l	8.67±1.67 ijk
NGB01215	Ke	5.67±0.33 a-f	3.00±0.58 e-i	8.67±0.67 f-k	5.67±0.33 c-f	4.00±1.00 jkl	9.67±0.67 h-k
NGB01216	Ke	7.33±0.33 a-d	3.00±1.00 e-i	10.33±0.67 d-i	4.00±0.58 def	3.33±0.33 kl	7.33±0.67 jk
NGB01217	Ke	4.67±0.67 c-g	3.33±0.33 d-i	8.00±0.58 h-k	4.67±1.20 def	5.00±0.58 g-l	9.67±1.67 h-k
NGB01220	Ke	4.67±0.88 c-g	3.33±0.33 d-i	8.00±0.58 h-k	4.67±0.67 def	4.67±0.33 h-l	9.33±0.88 ijk
NGB01221	Ke	5.00±0.58 c-g	3.33±0.33 d-i	8.33±0.67 g-k	4.67±0.33 def	4.00±0.58 jkl	8.67±0.88 ijk
NGB01222	Ke	6.33±0.33 a-f	2.67±0.33 e-k	9.00±0.58 f-j	4.00±1.00 def	3.33±0.67 kl	7.33±0.33 jk
NGB01226	Ke	5.67±0.67 c-f	2.00±0.58 g-k	7.67±0.33 i-l	5.00±0.58 def	3.33±0.33 kl	8.33±0.33 ijk
NG/AO/11/08/006	Ro	6.33±1.45 a-f	7.33±0.33 ab	13.67±1.20 a-d	5.67±0.88 c-f	9.33±1.33 a-d	15.00±1.73 b-f
MKD-Red-01	Ro	5.67±0.67 a-f	6.00±0.58 bcd	11.67±0.33 b-h	6.00±0.58 c-f	7.33±0.88 b-h	13.33±1.33 c-h
NIHORT-Red	Ro	6.33±1.45 a-f	6.33±1.20 bc	12.67±0.33 a-e	5.00±0.58 def	8.67±1.20 a-f	13.67±1.67 c-h
Ashwe-Green-01	Ro	8.67±0.88 ab	7.00±0.58 abc	15.00±1.00 ab	5.67±0.33 c-f	10.00±0.58 ab	15.67±0.67 a-e
NIHORT-Green	Ro	7.00±0.58 a-e	8.67±0.33 a	15.33±0.67 ab	6.67±0.33 cde	10.33±1.20 a	17.00±1.53 abc
NHGB/09/141	Jm	3.33±0.33 efg	2.00±0.58 g-k	5.33±0.88 klm	3.00±0.58 f	2.67±0.67 lm	5.67±0.33 k
NAC/NIH/040	Jm	2.00±0.56 gh	1.67±0.33 h-k	3.67±0.88 m	4.00±1.15 def	2.33±0.33 lm	6.33±1.45 k
NG/SA/07/0207	Jm	3.00±0.00 fgh	1.67±0.33 h-k	4.67±0.33 lm	3.33±0.88 f	2.33±0.33 lm	5.67±1.20 k
NG/OA/02/11/007	Jm	2.00±0.58 gh	2.00±0.00 h-k	4.00±0.58 m	3.00±0.58 f	2.67±0.33 lm	5.67±0.88 k
NHGB/09/145	Jm	3.33±0.58 efg	3.00±0.58 e-i	6.33±0.33 j-m	4.33±0.33 def	3.33±0.33 kl	7.67±0.33 jk
NGB01181	Ok	4.00±0.58 d-g	4.33±0.33 c-g	8.33±0.88 g-k	5.00±0.58 def	6.00±1.53 f-k	11.00±2.08 f-i
NGB01183	Ok	6.33±0.67 a-f	6.33±0.67 bc	12.67±1.33 a-e	6.00±0.58 c-f	7.67±0.33 b-g	13.67±0.33 c-h
NGB01184	Ok	6.00±1.15 a-f	6.00±0.58 bcd	12.00±1.53 b-f	7.00±0.58 bcd	7.00±1.00 c-i	14.00±0.58 c-g
NGB01186	Ok	7.00±0.56 a-e	5.33±0.33 b-e	12.33±0.67 a-f	7.33±0.33 bcd	7.00±1.15 c-i	14.33±0.88 c-f
NGB01190	Ok	6.67±0.88 a-f	6.00±0.58 bcd	12.67±0.67 a-e	7.00±0.58 bcd	7.00±0.58 c-i	14.00±0.00 c-g
NHAe47-4	Ok	7.33±1.45 a-f	7.33±0.33 a	16.67±1.20 a	10.00±0.58 a	9.00±0.58 a-e	19.00±1.00 a
LD-88	Ok	9.00±0.58 a	6.00±0.58 bcd	15.67±0.33 ab	9.00±0.58 ab	9.67±0.58 abc	18.67±0.88 a
Clemson spineless	Ok	7.00±1.15 a-e	4.67±0.33 c-g	11.67±1.20 b-h	8.67±0.33 abc	7.00±0.58 c-g	15.67±0.88 a-e
Dwarf LP	Ok	8.33±1.45 abc	6.00±0.58 bcd	14.33±0.88 abc	9.67±0.67 ab	6.33±1.20 e-j	16.00±0.58 a-d
Dogo	Ok	6.67±0.88 a-f	4.33±0.33 c-g	11.00±0.58 c-i	6.00±0.58 c-f	8.00±0.58 a-f	14.00±1.15 c-g
NGB01197	Ok	6.00±0.58 a-f	5.00±0.33 b-f	11.00±0.58 c-i	5.33±0.88 def	6.67±0.88 d-j	12.00±1.15 d-i
NGB01200	Ok	5.33±0.33 a-g	5.00±0.58 b-f	10.33±0.88 e-i	5.00±0.58 def	5.00±1.00 g-l	11.00±1.53 f-j
NGB01202	Ok	5.33±0.33 a-g	5.33±0.88 b-e	10.67±0.67 c-i	5.33±1.20 def	6.00±0.58 f-k	11.33±0.88 f-j
NGB01204	Ok	7.00±0.58 a-e	5.33±0.88 b-e	12.33±0.67 a-f	6.67±0.33 cde	7.33±0.33 b-h	14.00±0.00 c-g
NGB01205	Ok	6.67±0.33 a-f	5.00±0.58 b-e	11.67±0.88 b-h	5.33±0.67 def	6.33±0.33 e-j	11.67±0.33 e-j
Cv (%)		10.81	11.29	7.53	11.23	11.23	7.42

Means (± SEM) with the same lowercase alphabet in a column are not significantly different (SNK: P>0.05);
Cv (%) = Coefficient of variation CT=Crop type, Co=Cotton; Ke=Kenaf; Ro=Roselle; Jm=Jute mallow; Ok=Okra

However, on hosts like okra, the beetles also demonstrated frugivory (feeding on fruits). But all parts of the cotton genotypes showed no visible signs of flea beetle-induced damage all through the experiment in both years.

The number of leaves with the characteristic buckshot varied significantly in both years (2017: $F = 134.60$; df = 39, 78; $P < 0.001$, and 2018: $F = 49.83$; df = 39, 78; $P < 0.001$) (Table 2). More than 80% of all the crop leaves were damaged by the beetles except cotton and jute mallow leaves. Folivory (feeding on plant leaves) was highest on the kenaf genotypes in 2017 and 2018, but it was not significantly different from the damage observed on the leaves of okra and roselle genotypes. Buckshots were not found on leaves of all cotton genotypes, but for jute mallow, the damage ranged from 44.81 – 54.40% and 45.51 – 56.07% in 2017 and 2018 respectively. Leaf tissue removal by both species of the beetles was significantly higher [(2017: $F_3 = 86.59$; df = 39, 78; $P < 0.001$), (2018: $F = 97.51$; df = 39, 78; $P < 0.001$)] in the kenaf genotypes (41.33 - 62.17 and 48.12 - 58.62% in 2017 and 2018 respectively) than other crops. The leaves of the cotton genotypes were intact in both years. Leaf damage was mostly in the order of kenaf > okra > roselle > jute mallow > cotton.

Leaf abscission ranged from 0 – 59.14% and 0 – 59.05% in 2017 and 2018 respectively, with the NGB01220 genotype of kenaf losing the highest number of leaves in both years [(2017: $F = 152.75$; df = 39, 78; $P < 0.001$), (2018: $F = 126.47$; df = 39, 78; $P < 0.001$)] (Table 3). But flea beetle-induced leaf abscission was not observed on any of the cotton genotypes in both years. In addition, more than 40% of leaves from kenaf genotypes were lost due to stress induced by the herbivores and it was significantly higher compared to abscission observed in okra [25.25 -33.11% (2017), 22.25 - 33.33% (2018)], roselle

Table 2: Leaf damage induced by *Podagrica* spp. on different Malvaceae crops at Abeokuta, Nigeria

		Damaged leaves per plant (%)		Leaf area damaged (%)	
Genotypes	CT	2017	2018	2017	2018
10-Zamfara	Co	0.00±0.00g	0.00±0.00c	0.00±0.00g	0.00±0.00i
37-Gusau	Co	0.00±0.00g	0.00±0.00c	0.00±0.00g	0.00±0.00i
9-Maru Zamfara	Co	0.00±0.00g	0.00±0.00c	0.00±0.00g	0.00±0.00i
NG/SA/JAN/09/150	Co	0.00±0.00g	0.00±0.00c	0.00±0.00g	0.00±0.00i
MCt-11	Co	0.00±0.00g	0.00±0.00c	0.00±0.00g	0.00±0.00i
NGB01212	Ke	99.13±0.87a	97.62±1.50a	41.33±9.20bc	48.12±2.20b
NGB01213	Ke	100.00±0.00a	98.26±0.94a	59.39±4.73a	55.38±2.82ab
NGB01214	Ke	95.87±3.02abc	97.75±1.38a	63.49±1.84a	56.06±3.22ab
NGB01215	Ke	98.33±1.67a	98.18±1.00a	53.81±3.42a	58.62±3.42a
NGB01216	Ke	99.40±0.60a	98.74±0.63a	41.33±9.20bc	48.12±2.20b
NGB01217	Ke	100.00±0.00a	98.20±0.99a	58.00±4.04a	58.03±3.76ab
NGB01220	Ke	97.92±1.08a	96.34±2.72a	55.57±3.36a	57.09±3.77ab
NGB01221	Ke	98.29±1.71a	98.57±0.72a	57.32±4.13a	57.40±3.43ab
NGB01222	Ke	100.00±0.00a	97.11±1.98a	62.17±6.11a	53.70±1.22ab
NGB01226	Ke	99.61±0.39a	97.82±1.32a	56.17±3.23a	55.21±2.77ab
NG/AO/11/08/006	Ro	98.53±1.47a	98.95±0.58a	26.67±0.88bc	31.93±0.58c
MKD-Red-01	Ro	100.00±0.00a	98.23±0.96a	26.87±1.67bc	29.24±1.50cd
NIHORT-Red	Ro	100.00±0.00a	99.33±0.67a	26.59±0.98bc	30.65±1.31c
Ashwe-Green-01	Ro	99.13±0.87a	94.50±4.54a	23.33±0.67cde	29.27±0.68cd
NIHORT-Green	Ro	98.92±1.08a	94.17±4.87a	25.67±3.71bcd	30.62±0.66cd
NHGB/09/141	Jm	44.81±0.19f	45.41±0.41b	13.00±1.15def	14.00±1.15fgh
NAC/NIH/040	Jm	46.20±3.97f	49.64±4.64b	12.19±1.24ef	14.00±2.08fgh
NG/SA/07/0207	Jm	45.32±6.73f	48.72±5.72b	11.67±0.67ef	15.00±1.15e-g
NG/OA/02/11/007	Jm	46.96±7.04f	45.38±8.62b	9.82±0.83fg	12.65±1.77gh
NHGB/09/145	Jm	54.40±5.26f	56.07±1.07b	12.00±1.15ef	10.33±0.67h
NGB01181	Ok	80.67±1.45e	81.11±3.89a	20.00±0.58c-f	13.76±5.15fgh
NGB01183	Ok	87.45±2.55a-e	84.07±5.93a	21.82±1.08c-f	19.38±2.26e-g
NGB01184	Ok	85.30±3.15cde	88.61±3.61a	23.48±0.63cde	24.97±4.03c-f
NGB01186	Ok	86.96±3.02b-e	89.33±0.67a	22.20±0.70c-f	24.33±3.71c-f
NGB01190	Ok	95.00±2.89ab	86.06±8.94a	25.26±2.21bcd	22.60±3.45c-g
NHAe47-4	Ok	100.00±0.00a	98.33±1.67a	33.09±0.79bc	33.33±0.88c
LD-88	Ok	100.00±0.00a	96.67±1.67a	30.83±1.53bc	31.00±0.58c
Clemson spineless	Ok	91.67±1.67a-d	88.21±1.79a	26.31±2.41bc	30.08±1.57c
Dwarf LP	Ok	100.00±0.00a	93.33±3.33a	37.00±2.08b	31.89±2.51c
Dogo	Ok	87.78±1.47a-e	85.40±4.60a	25.59±3.26bcd	24.15±1.09c-f
NGB01197	Ok	83.33±1.67de	83.96±8.04a	21.42±0.61c-f	17.81±1.70e-g
NGB01200	Ok	84.24±1.85de	87.22±2.22a	19.63±0.61c-f	22.40±2.37c-g
NGB01202	Ok	80.00±2.62e	88.00±6.00a	20.67±0.88c-f	22.33±0.67d-g
NGB01204	Ok	81.00±3.21de	84.00±4.00a	22.33±0.88c-f	24.33±0.67d-f
NGB01205	Ok	83.00±2.89de	85.77±2.77a	22.00±0.58c-f	22.00±2.08c-g
Cv (%)		6.66	10.69	9.43	8.67

Means (± SEM) with the same lowercase alphabet in a column are not significantly different (SNK: $P>0.05$);
Cv (%) = Coefficient of variation CT=Crop type, Co=Cotton; Ke=Kenaf; Ro=Roselle; Jm=Jute mallow; Ok=Okra

[25.80 - 29.81% (2017), 21.61 - 26.86% (2018)] and jute mallow [10.40 -21.90% (2017), 11.67 - 21.33% (2018)] plots.

Fruit feeding was observed only on the okra genotypes and it ranged from 28.22 – 78.33% and 28.22 -54.67% in 2017 and 2018 respectively. Fruits from other crop types remained undamaged all through the reproductive growth stage. The nature of beetle-induced fruit damage comprises mainly of incisions on the exocarp and they are usually marked by visible brownish-black lesions when those spots heal. The percentage of damaged NHAe47-4 fruit fruits was significantly higher (2017: $F = 98.75$; df = 39, 78; $P < 0.001$, 2018: $F = 257.86$; df = 39, 78; $P < 0.001$)] when compared with other okra genotypes in both years.

Loss of crop stands was observed only in kenaf, roselle and *A. esculentus* (okra) plots. The number of affected stands varied significantly [(2017: $F = 11.36$; df = 39, 78; $P < 0.001$) and (2018: $F = 15.12$; df = 39, 78; $P < 0.001$)] among the Malvaceae crops (Table 4). The highest loss was observed in Dwarf LP (okra) plots and it was significantly different from the loss observed in other crop plots. Most of the losses in stands occurred between 1 and 5 WAS. However, all the genotypes demonstrated the capacity of surviving stress induced by the beetles after 5 weeks of crop establishment in the field except Dwarf LP variety of okra. No flea beetle-induced loss in crop stands occurred in plots with cotton, jute mallow and A. *caillei* (okra).

Correlations Between Flea Beetle Infestation and Damage Parameters

There were positive associations between the population of *Podagrica* spp. and the number of damaged leaves per plant ($r = 0.864$, $n = 120$, $P < 0.001$), leaf area damaged per plant ($r = 0.507$, $n = 120$, $P < 0.001$), damaged fruits per plant ($r = 0.562$, $n = 120$, $P < 0.001$), leaf abscission per plant ($r = 0.535$, $n = 120$,

Table 3: Leaf abscission and fruit damage caused by *Podagrica* spp. on different Malvaceae crops at Abeokuta, Nigeria

		Leaf abscission per plant (%)		Damaged fruits per plant (%)	
Genotypes	CT	2017	2018	2017	2018
10-Zamfara	Co	0.00±0.00n	0.00±0.00i	0.00±0.00f	0.00±0.00f
37-Gusau	Co	0.00±0.00n	0.00±0.00i	0.00±0.00f	0.00±0.00f
9-Maru Zamfara	Co	0.00±0.00n	0.00±0.00i	0.00±0.00f	0.00±0.00f
NG/SA/JAN/09/150	Co	0.00±0.00n	0.00±0.00i	0.00±0.00f	0.00±0.00f
MCt-11	Co	0.00±0.00n	0.00±0.00i	0.00±0.00f	0.00±0.00f
NGB01212	Ke	56.79±2.60b	56.21±3.85b	0.00±0.00f	0.00±0.00f
NGB01213	Ke	37.78±1.15d-g	45.00±1.00c	0.00±0.00f	0.00±0.00f
NGB01214	Ke	56.79±2.60b	56.21±3.85b	0.00±0.00f	0.00±0.00f
NGB01215	Ke	56.79±2.60b	56.21±3.85b	0.00±0.00f	0.00±0.00f
NGB01216	Ke	36.12±2.26e-i	44.00±5.57c	0.00±0.00f	0.00±0.00f
NGB01217	Ke	44.67±2.91cd	55.00±1.73b	0.00±0.00f	0.00±0.00f
NGB01220	Ke	59.14±3.32a	59.05±5.24a	0.00±0.00f	0.00±0.00f
NGB01221	Ke	39.53±2.08c-g	45.67±4.26c	0.00±0.00f	0.00±0.00f
NGB01222	Ke	46.03±2.30c	50.67±2.33bc	0.00±0.00f	0.00±0.00f
NGB01226	Ke	58.71±3.16a	58.57±5.00a	0.00±0.00f	0.00±0.00f
NG/AO/11/08/006	Ro	25.92±1.50kl	21.61±0.87fg	0.00±0.00f	0.00±0.00f
MKD-Red-01	Ro	27.33±1.86jkl	24.39±0.87def	0.00±0.00f	0.00±0.00f
NIHORT-Red	Ro	29.81±1.48h-l	26.86±1.61def	0.00±0.00f	0.00±0.00f
Ashwe-Green-01	Ro	28.32±1.45j-l	24.73±0.90def	0.00±0.00f	0.00±0.00f
NIHORT-Green	Ro	25.80±1.60kl	22.28±0.89efg	0.00±0.00f	0.00±0.00f
NHGB/09/141	Jm	10.40±0.83m	11.67±0.33h	0.00±0.00f	0.00±0.00f
NAC/NIH/040	Jm	13.61±1.31m	13.91±0.96gh	0.00±0.00f	0.00±0.00f
NG/SA/07/0207	Jm	21.90±0.49l	21.33±2.03fg	0.00±0.00f	0.00±0.00f
NG/OA/02/11/007	Jm	13.18±0.61m	12.52±0.87h	0.00±0.00f	0.00±0.00f
NHGB/09/145	Jm	12.63±0.69m	12.65±0.90h	0.00±0.00f	0.00±0.00f
NGB01181	Ok	33.11±0.11f-k	32.11±1.06def	46.67±5.70cd	31.00±1.00de
NGB01183	Ok	29.33±2.96h-l	31.59±2.09def	41.33±5.55cde	28.44±2.51e
NGB01184	Ok	29.33±3.53h-l	32.72±1.98de	46.33±14.38cd	36.00±2.31cde
NGB01186	Ok	30.33±3.53h-l	32.76±2.88de	44.33±8.09 cde	40.00±5.00c
NGB01190	Ok	31.00±1.73h-k	13.33±6.67gh	37.11±1.86de	31.09±1.99de
NHAe47-4	Ok	36.67±2.33e-h	34.21±0.61d	78.33±3.33a	54.67±5.78a
LD-88	Ok	32.14±1.03h-k	33.00±1.00de	72.57±5.60b	50.17±5.42b
Clemson spineless	Ok	28.33±2.40j-k	33.33±0.33d	55.00±2.89c	48.71±4.22b
Dwarf LP	Ok	29.44±1.97h-l	26.52±1.34def	55.00±2.89c	48.71±4.22b
Dogo	Ok	29.44±1.97h-l	26.52±1.34def	55.56±6.26c	48.52±4.55b
NGB01197	Ok	25.25±2.56kl	22.25±0.90efg	38.33±2.19cde	41.40±1.53c
NGB01200	Ok	31.39±1.15h-k	30.06±0.97def	39.33±6.33cde	40.44±1.82c
NGB01202	Ok	30.67±1.76h-l	29.61±1.40def	39.33±4.84cde	38.78±0.40cd
NGB01204	Ok	31.00±1.00h-k	27.67±1.20def	28.22±4.37e	28.22±1.82e
NGB01205	Ok	29.39±1.45h-l	27.14±1.86def	30.00±7.64de	31.00±2.08de
Cv (%)		6.38	7.28	33.85	14.21

Means (± SEM) with the same lowercase alphabet in a column are not significantly different (SNK: $P>0.05$); Cv (%) = Coefficient of variation CT=Crop type, Co=Cotton; Ke=Kenaf; Ro=Roselle; Jm=Jute mallow; Ok=Okra

$P < 0.001$) and the number of loss stands ($r = 0.593$, $n = 120$, $P < 0.001$) in 2017 (Table 5).

Similarly, the population of the beetles per plant was positively correlated with the number of damaged leaves per plant ($r = 0.803$, $n = 120$, $P < 0.001$), leaf area loss ($r = 0.452$, $n = 120$, $P = 0.0261$), damaged fruits per plant ($r = 0.627$, $n = 120$, $P < 0.001$), leaf abscission per plant ($r = 0.467$, $n = 120$, $P = 0.0203$) and loss stands ($r = 0.503$, $n = 120$, $P < 0.001$) in 2018.

Ranking of the Tested Crops Using Smith-Hazel's Selection Index

A discriminant function ($H = 1.38\ X_1 + 0.76\ X_2 + 1.03\ X_3 + 1.31\ X_4 + 0.89\ X_5 + 0.83\ X_6$) was generated using the infestation and damaged parameters measured. The result showed that the NHAe47-4, LD-88, and Dwarf LP okra genotypes were the first three Malvaceae genotypes most susceptible to the *Podagrica* spp., while the cotton genotypes were the least in order of descending susceptibility (Table 6).

DISCUSSION

Apart from the cotton, all crops evaluated could be categorized as susceptible to *P. uniforma* and *P. sjostedti* attacks due to the high infestation and damage levels observed. This further confirms previous reports on the economic damage caused by the attacks of the beetles on crops in the Malvaceae family (Echezona *et al.*, 2010; Pitan & Adewole, 2011; Pitan & Ekoja, 2011; Ekoja *et al.*, 2022). Interestingly, all the cotton genotypes used in the study seem not to be attractive to the beetles, as there were no visible symptoms of damage on all parts of the crops. This may have arisen from the complex interplay of physical and chemically derived barriers which deterred the herbivores from approaching and consuming the cotton genotypes. This outcome was contrary to the findings of Pitan

Table 4: Loss in crop stands caused by *Podagrica* spp. on Malvaceae crops field at Abeokuta, Nigeria

Genotypes	CT	2017	2018
10-Zamfara	Co	0.00±0.00i	0.00±0.00h
37-Gusau	Co	0.00±0.00i	0.00±0.00h
9-Maru Zamfara	Co	0.00±0.00i	0.00±0.00h
NG/SA/JAN/09/150	Co	0.00±0.00i	0.00±0.00h
MCt-11	Co	0.00±0.00i	0.00±0.00h
NGB01212	Ke	20.00±5.77b	23.33±3.33b
NGB01213	Ke	16.67±3.33bc	23.33±3.33b
NGB01214	Ke	16.67±3.33bc	20.00±5.77bc
NGB01215	Ke	16.67±3.33bc	20.00±5.77bc
NGB01216	Ke	16.67±3.33bc	23.33±3.33b
NGB01217	Ke	16.67±3.33bc	23.33±3.33b
NGB01220	Ke	13.33±3.33bcd	20.00±5.77bc
NGB01221	Ke	20.00±3.33b	23.33±3.33b
NGB01222	Ke	13.33±3.33bcd	20.00±5.77bc
NGB01226	Ke	13.33±3.33bcd	16.67±3.33bcd
NG/AO/11/08/006	Ro	13.33±3.33bcd	13.33±3.33cde
MKD-Red-01	Ro	13.33±3.33bcd	13.33±3.33cde
NIHORT-Red	Ro	10.00±5.77cd	13.33±3.33cde
Ashwe-Green-01	Ro	3.33±3.33d-h	3.33±3.33d-h
NIHORT-Green	Ro	3.33±3.33d-h	6.67±3.33e-h
NHGB/09/141	Jm	0.00±0.00i	0.00±0.00h
NAC/NIH/040	Jm	0.00±0.00i	0.00±0.00h
NG/SA/07/0207	Jm	0.00±0.00i	0.00±0.00h
NG/OA/02/11/007	Jm	0.00±0.00i	0.00±0.00h
NHGB/09/145	Jm	0.00±0.00i	0.00±0.00h
NGB01181	Ok	6.67±3.33c-h	10.00±5.77d-g
NGB01183	Ok	13.00±6.67bcd	10.00±5.77d-g
NGB01184	Ok	10.00±5.77b-f	10.00±5.77d-g
NGB01186	Ok	13.33±3.33bcd	13.33±3.33cde
NGB01190	Ok	13.33±3.33bcd	13.33±3.33cde
NHAe47-4	Ok	16.67±3.33bc	23.33±3.33b
LD-88	Ok	13.33±6.67bcd	16.67±3.33bcd
Clemson spineless	Ok	13.33±6.67bcd	16.67±3.33bcd
Dwarf LP	Ok	30.00±5.77a	33.33±3.33a
Dogo	Ok	13.33±6.67bcd	16.67±3.33bcd
NGB01197	Ok	0.00±0.00i	0.00±0.00h
NGB01200	Ok	0.00±0.00i	0.00±0.00h
NGB01202	Ok	0.00±0.00i	0.00±0.00h
NGB01204	Ok	0.00±0.00i	0.00±0.00h
NGB01205	Ok	0.00±0.00i	0.00±0.00h
Cv (%)		25.03	19.70

Means (± SEM) with the same lowercase alphabet in a column are not significantly different (SNK: P>0.05); Cv (%) = Coefficient of variation CT=Crop type, Co=Cotton; Ke=Kenaf; Ro=Roselle; Jm=Jute mallow; Ok=Okra

Table 5: Pearson's correlation between *Podagrica* spp. population and damage parameters

	Population of *Podagrica* spp.	
Damage/loss (%)	2017	2018
Damaged leaves per plant	0.864**	0.803**
Leaf area loss	0.407**	0.352*
Damaged fruits per plant	0.535**	0.367*
Leaf abscission per plant	0.562**	0.627**
Loss stands	0.493**	0.403**

*, ** = Correlation is significant at $P<0.05$ and $P<0.001$ level respectively.
Similarly, the population of the beetles per plant was positively correlated with the number of damaged leaves per plant (r=0.803, n=120, $P<0.001$), leaf area loss (r=0.452, n=120, P=0.0261), damaged fruits per plant (r=0.627, n=120, $P<0.001$), leaf abscission per plant (r=0.467, n=120, P=0.0203) and loss stands (r=0.503, n=120, $P<0.001$) in 2018

and Adewole (2011) who reported leaf feeding by *P. sjostedti* in cotton plots.

Furthermore, the host preference study carried out by Abebe *et al*. (2021) showed that the cotton varieties tested were susceptible to *P. puncticollis* herbivory. This contrast in the response of different *Podagrica* species to cotton suggests that host preference may differ significantly among the insects at the species level. In addition, this non-preference of cotton may also be an outcome of the intrinsic resistance exhibited by the crops. However, isolated investigations involving a single variety or many varieties of cotton will provide a clearer picture of the innate capacity of the crop to resist herbivory induced by *P. uniforma* and *P. sjostedti*. In the meantime, this intrinsic resistance could be exploited in insect pest management by intercropping cotton with susceptible crops such as okra (i.e. promoting interspecies diversity within a crop field) to reduce flea beetle herbivory. This practice has been reported to mitigate damage by insect pests, and improve yield in an agricultural system (Tooker & Frank, 2012; Yang *et al*., 2019; Field *et al*., 2020).

The beetles occupied the adaxial surface of plant leaves from the late evening (sunset) to the early hours of the morning (before sunrise). Both feeding and mating activities seem to occur more during this period. But when the sun rises and the temperature of the environment increases, the beetles retreat to the abaxial portion of crop leaves, neighbouring plots with broadleaf plants, and field borders with thicker vegetation. This exothermic response to temperature affects the beetles' feeding and mating behaviours as well as their population on the hosts. Bunn *et al*. (2015) also gave a similar description of flea beetles' flight activities during unfavourable conditions within the environment. This also implies that successful pest management tactics for *Podagrica* spp. should target the insects during periods between the late evenings to early hours of the day to maximize control. The Malvaceae crops with broad leaves (such as okra and roselle) received more visitations and leaf tissue consumption than other crops with somewhat narrow-leaf areas (such as jute mallow and kenaf). The large leaf surfaces may have provided both food and shelter for the insects. Bell (1990) reported that the availability/absence of food, shelter, and oviposition sites have a significant influence on the behaviour and population of insects in an ecosystem.

In a mixed crop scenario, the cues released by some plants have been reported to mask the effect of those released by other plants, and under such circumstances, associated insects may find it difficult to locate their hosts to feed and reproduce (Altieri 1986; Sujayanand *et al*., 2015). But our results showed that when the odour is emanating from crops that are within the host range of a specialist herbivore like *P. uniforma* and *P. sjostedti*, the beetles in neighbouring vegetation gravitate towards the blend of odours (volatile cues from the crop mixtures) coming from the field, hence the high level of infestation and damage observed in the study. This was similar to the findings of Najar-Rodriguez *et al*. (2010) and Thoming and Norli (2015).

Table 6: Susceptibility ranking of fourty Malvaceae crops based on *Podagrica* spp. infestation and damage parameters

Genotypes	CT	PP	DL	LAD	LAB	DF	LS	*H*	σRank
10-Zamfara	Co	0.46	0.00	0.00	0.00	0.00	0.00	0.46	36th
37-Gusau	Co	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38th
9-Maru Zamfara	Co	0.46	0.00	0.00	0.00	0.00	0.00	0.46	36th
NG/SA/JAN/09/150	Co	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38th
MCt-11	Co	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38th
NGB01212	Ke	12.65	74.67	57.90	74.02	0.00	13.84	233.08	6th
NGB01213	Ke	11.96	75.34	59.11	54.22	0.00	16.60	217.22	11th
NGB01214	Ke	12.19	75.29	59.00	74.02	0.00	13.84	234.33	5th
NGB01215	Ke	12.19	74.75	57.00	74.02	0.00	16.60	234.55	4th
NGB01216	Ke	11.96	73.58	61.57	52.48	0.00	13.84	213.42	14th
NGB01217	Ke	12.19	75.32	59.76	65.28	0.00	13.84	226.38	8th
NGB01220	Ke	11.96	73.82	58.02	77.41	0.00	11.06	232.27	7th
NGB01221	Ke	11.73	74.81	59.08	55.81	0.00	16.60	218.02	10th
NGB01222	Ke	11.27	74.90	59.67	63.34	0.00	11.06	220.24	9th
NGB01226	Ke	11.04	75.02	57.36	55.00	0.00	15.21	213.64	13th
NG/AO/11/08/006	Ro	19.78	75.04	30.18	31.13	0.00	11.06	167.20	25th
MKD-Red-01	Ro	17.25	75.33	28.90	33.88	0.00	11.06	166.41	27th
NIHORT-Red	Ro	18.17	75.75	29.48	37.12	0.00	8.30	168.82	23rd
Ashwe-Green-01	Ro	21.16	73.58	27.09	34.75	0.00	2.76	159.34	29th
NIHORT-Green	Ro	22.31	73.37	28.99	31.49	0.00	2.76	158.93	30th
NHGB/09/141	Jm	7.59	34.28	13.91	14.46	0.00	0.00	70.23	34th
NAC/NIH/040	Jm	6.90	36.42	13.49	18.03	0.00	0.00	74.83	33rd
NG/SA/07/0207	Jm	7.13	35.74	13.74	28.32	0.00	0.00	84.92	31st
NG/OA/02/11/007	Jm	6.67	35.09	11.57	16.83	0.00	0.00	70.17	35th
NHGB/09/145	Jm	9.66	41.98	11.50	16.56	0.00	0.00	79.70	32nd
NGB01181	Ok	13.34	61.48	17.39	42.72	34.56	5.54	175.02	22nd
NGB01183	Ok	18.17	65.18	21.22	39.90	31.05	10.79	186.31	18th
NGB01184	Ok	17.94	66.09	24.95	40.64	36.64	8.30	194.56	17th
NGB01186	Ok	18.40	66.99	23.96	41.32	37.53	11.06	199.26	16th
NGB01190	Ok	18.40	68.80	24.65	29.04	30.35	11.06	182.30	19th
NHAe47-4	Ok	24.61	75.37	34.21	46.43	59.19	13.84	253.63	1st
LD-88	Ok	23.69	74.73	31.84	42.67	54.62	11.06	238.62	2nd
Clemson spineless	Ok	18.86	68.35	29.04	40.39	46.15	11.06	213.86	12th
Dwarf LP	Ok	20.93	73.47	40.00	36.65	46.15	20.75	237.95	3rd
Dogo	Ok	17.25	65.81	25.62	36.65	46.32	11.06	202.71	15th
NGB01197	Ok	15.87	63.57	20.20	31.11	35.48	0.00	166.24	28th
NGB01200	Ok	14.72	65.15	21.65	40.25	35.50	0.00	177.27	20th
NGB01202	Ok	15.18	63.84	22.15	39.48	34.76	0.00	175.41	21st
NGB01204	Ok	18.17	62.70	24.03	38.43	25.12	0.00	168.44	24th
NGB01205	Ok	16.10	64.13	22.66	37.03	27.15	0.00	167.07	26th

$H = {}^{\lambda}1.38\ X_1 + 0.76\ X_2 + 1.03\ X_{3+} 1.31\ X_4 + 0.89\ X_5 + 0.83\ X_6$

$X_{1=}$PP [Population of *Podagrica* spp.]; $X_{2=}$DL [Number of damaged leaves (%)]; $X_{3=}$LAD [Leaf area damaged (%)]; $X_{4=}$LAB [Leaf abscission (%)]; $X_{5=}$DF [Damaged fruits (%)]; $X_{6=}$LS (Loss in crop stands (%)]; $^{\lambda}$ = coefficient;
$^{\sigma}$ = Descending order of susceptibility; CT=Crop type, Co=Cotton; Ke=Kenaf; Ro=Roselle; Jm=Jute mallow; Ok=Okra

The responses to different Malvaceae crops demonstrated by *P. uniforma* and *P. sjostedti* under field conditions clearly showed their preference for okra followed by kenaf and roselle. Jute mallow was the least infested and damaged crop type. While okra received more visitations by the beetles, the kenaf genotypes received higher leaf tissue consumption from the beetle. The superiority of okra in attracting more beetles may be due to its genetic capacity to produce leaves that are wider in size compared with other crop types. The broad leaves may have provided better shelter and food for the insects (Bell, 1990). It is also important to note that the beetles' preference for some crops as demonstrated in this polyculture of Malvaceae crops, may not be sustained in a monoculture of each crop. Studies have shown that in a monocrop scenario, some insects could be compelled to consume less or non-preferred crops (Peacock & Herrick, 2000; McArt & Thaler, 2013), especially when a more susceptible/preferred neighbour is absent. More experiments are needed to demonstrate the potential of okra, kenaf and roselle as trap crops for the field management of *P. uniforma* and *P. sjostedti*. Future studies will also be focused on the identification of volatile organic compounds that may have mediated attraction and deterrence responses of the beetles with a view of developing a semiochemical-based attractant/repellent to manage the beetles.

Leaf tissue removal by insects has been reported to reduce leaf biomass available for photosynthesis (Delaney *et al*., 2008), disrupt the photosynthetic capacity of the remaining undamaged leaf tissues (Watling & Press, 2001; Delaney *et al*., 2008) increase the rate of transpiration (Aldea *et al*., 2005), reduces CO_2 gain (Barron-Gafford *et al*., 2012), increases leaf water loss (Meyer, 1992) and exposes the plant to attack from pathogenic organisms (Orozco-Cardenas & Ryan, 1999). Stress originating from the disruption of a combination of these processes and other beetle-induced physiological perturbations may be responsible for the high level of leaf abscissions and loss in crop stands observed in the study. In addition, shoot growth and development are critical determinants of crop productivity (Yang *et al*., 2021). The copious leaf tissue consumption by the flea beetle portends a significant loss in crop biomass and fruit yield in susceptible Malvaceae crops. Hence, it is essential for producers of okra, kenaf, roselle, and jute mallow to deploy control measures early in their field to reduce flea beetle infestation, improve crop performance and prevent significant loss in yield.

Fruits of most Malvaceae crops tested were well protected by spiny trichomes. However, the avoidance of frugivory on cotton, kenaf, roselle, and jute mallow fruits may be due to a combination of physical and chemical barriers innate in those crop types as reported by (Wheeler & Krimmel, 2015). This became clearer as we observed that the spiny trichomes on okra fruits did not forestall fruit feeding by the beetles. In addition, both genetic and functional traits inherent in cotton, jute mallow and *A. caillei* (okra) may have facilitated their ability to withstand the level of herbivory induced by the beetles and prevented loss in crop stands. Generally, the population of crops in a field at maturity is the critical determinant of harvest (Thelen, 2007).

CONCLUSIONS

Our result showed that all the Malvaceae crops evaluated were susceptible to infestation and damage induced by *P. uniforma* and *P. sjostedti* except the cotton genotypes. The okra genotypes played host to more flea beetles than the other crops, but leaf tissue consumption by the arthropod was higher in the kenaf genotypes. In order of descending susceptibility, NHAe47-4, LD-88 and Dwarf LP genotypes of okra were the first three most susceptible crops, but the cotton genotypes were the least preferred crops. These results may be helpful when developing a sustainable pest management strategy for *P. uniforma* and *P. sjostedti* in the Malvaceae crop fields. For instance, the most preferred crops, such as okra, could be used as a trap crop; their volatile profile could provide a lead for the development of a host-based semiochemical lure for the beetles; crop producers planning a monoculture of the susceptible crops should also plan to make additional investment in control of the pest to avoid loss in crop stands and yield. However, the cotton genotypes could be incorporated in mixtures of Malvaceae crops to reduce herbivory by *Podagrica* spp, their volatile profile could also provide information on compounds that could be used to develop a potent repellent against *P. uniforma* and *P. sjostedti*.

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