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Marcus Ramdwar, Wayne Ganpat, Jesse Harripersad, Wendy Isaac and Donald Palmer

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*Corresponding author: Marcus Ramdwar, Assistant Professor Agriculture Biosciences Agriculture and Food Technologies, University of Trinidad and Tobago, ECIAF Campus, Caroni North Bank Road, Centeno, Arima, Trinidad
E-mail: marcusramdwar@gmail.com

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The preferential feeding habits of *Achatina (Lissachatina) fulica* (Bowdich) on selected crops grown and weeds found in Trinidad, West Indies

Marcus Ramdwar^{1*}, Wayne Ganpat², Jesse Harripersad¹, Wendy Isaac³ and Donald Palmer⁴

Abstract: A study was conducted to determine the preferential feeding habits of the Giant African Snail (GAS) *Achatina (Lissachatina) fulica* (Bowdich) on selected crops and selected weeds found in Trinidad, West Indies. The intraspecific plant vulnerabilities such as vegetative (leaves) and reproductive structures (flowers and pods/fruits) of ochro, pumpkin, seim, papaya and eggplant were investigated. Additionally, the preference for leaves of selected weeds (*Amaranth spp*, *Portulaca oleracea* and *Cleome spp*) and root crops (cassava, sweet potato and dasheen) were investigated. In determining the intraspecific preference for the parts within a crop, 10 g of each component (leaves, flowers and pods) were placed into a chamber with three adult GAS, averaging 5 cm in length and replicated five times for each crop. The GAS had the option to choose between vegetative and reproductive structures. Similarly, 10 g of leaves for each weed were placed into a chamber with three adult snails and replicated five times. In determining the vulnerabilities for the leaves of the selected root crops, the treatment and replicates were similar to the weeds in that the GAS also had the option to select among the leaves of the root crops presented. The amount of plant material consumed after 24 and 48 h was recorded and statistically analyzed using Statistical Package for Student of Social Sciences

ABOUT THE AUTHORS

Dr. Marcus Ramdwar is an assistant professor of agriculture at the University of Trinidad and Tobago (UTT). His research focus is related to food security, crop production and crop protection. His research also includes studies on farmers' groups, sustainable approaches to control the Giant African Snail and utilisation of the Sargassum seaweed.

Mr. Jesse Harripersad is a farmer and a student in the final year of his B.Sc. Crop Science and Technology degree at the University of Trinidad and Tobago (UTT).

Dr. Wayne Ganpat is an agricultural extension and education expert and is also the current Dean of the Faculty of Food and Agriculture at the University of the West Indies.

Dr. Isaac is a senior lecturer and Mr. Donald Palmer is a part-time lecturer in the Faculty of Food and Agriculture, at the University of the West Indies St Augustine Campus, Trinidad, West Indies.

PUBLIC INTEREST STATEMENT

The Giant African Snail (GAS) is a native of East Africa and was discovered in Trinidad in 2008 in Diego Martin. The GAS is the second worst invasive alien species in the world. As of August 2017, the snail had infested over 17 areas and is becoming very difficult to contain and control. This snail feeds on over 500 species of vegetation, and given that Trinidad is self-sufficient in vegetable production, the burden of this pest can be a significant threat to Trinidad's domestic food security. The GAS can be considered the only agricultural polyphagous herbivorous pest which is a threat to public health since it is a known vector of the rat lungworm which causes eosinophilic meningoencephalitis in humans. The study can provide insight into the preferences for selected parts within a plant which can be incorporated into the design for more target-specific crop protection approaches.

(SPSS) version 22. The results of the study showed that the GAS exhibit significant preferences ($p < .05$) for components of plant parts within a plant and for consuming more leaves of one type of weed and root crop over another. The study concluded that by knowing the specific vulnerabilities of a crop to the GAS, the crop protection approaches to controlling the GAS in a cropping system can be more appropriately redesigned and precision based.

Subjects: Agriculture & Environmental Sciences; Botany; Plant & Animal Ecology

Keywords: Giant African Snail; crop protection; selective; plant parts

1. Introduction

The giant African snail (GAS), *Achatina (Lissachatina) fulica* (Bowdich), is a highly invasive terrestrial snail native to East Africa (Raut & Barker, 2002; Sarma, Munsu, & Ananthram, 2015). According to Bhattacharyya, Das, Mishra, Nath, and Bhagawati (2014), due to several factors such as high reproductive capacity, voracious feeding habit, inadequate quarantine management and human aided dispersal, the GAS can be found widely distributed and no longer limited to their region of origin. In 1984, the GAS was established on the Caribbean island of Guadeloupe, by 1988 on Martinique, and subsequently on Barbados and Saint Lucia (Raut & Barker, 2002). In October 2008, the snail was discovered in the Republic of Trinidad at one confined location; however, 17 new areas of infestations have been discovered within Trinidad in agricultural and non-agricultural districts.

The GAS is a notorious generalist that consumes over 500 plant species and ranks consistently among the world's most invasive pests (Lowe, Browne, Boudjelas, & De Poorter, 2000; Simberloff, 2003). Given the destructive ecological characteristic of this pest, the Global Invasive Species Database has ranked it among the "100 Worst Alien Invasive Species" (Invasive Species Specialist Group, 2012). This snail is of significant importance to tropical agricultural productivity (Raut & Barker, 2002) and also to human health since it is known to be a vector of the rat lungworm, *Angiostrongylus cantonensis*, which causes eosinophilic meningoencephalitis in humans (Alicata, 1991; Prociw, Spratt & Carlisle, 2000). The GAS is a defoliator and exhibits extensive rasping (scraping) feeding habits (Bhattacharyya et al., 2014).

Field and on-farm feed preference studies (Chevalier, Desbuquois, Papineau, & Charrier, 2000; Chevalier, Le Coz-Bouhnik, & Charrier, 2003; Ebenso & Adeyemo, 2011; Iglesias & Castillejo, 1999) have demonstrated the capacity of snails to choose their feed when given free choice feeding and to retain memories of preferred feeds. The location of food by the GAS is powered by its sense of smell (Albuquerque, Peso-Aguiar, & Assunção-Albuquerque, 2008) and possesses a long-lasting memory of the odours of plants that are used as food (Croll & Chase, 1977). The GAS and other gastropods use chemoreception to locate distant sources of food and to discriminate between potential foods using taste and smell (Croll, 1983). Additionally, Croll (1983) reported that given an abundant supply of different food sources, gastropods actively select among choices since not all plants in proximity necessarily represent a preferred food item.

Given the small-sized holdings of crop farmers in Trinidad and the close proximity of crop cultivation from one crop farmer to another, there may be preferential crop types as preferred food sources for the GAS. The current study attempts to investigate the food preference for GAS in relation to plant structures: leaves, flowers and pods/fruits within a selected crop types in order to assess the crop intra-specific vulnerabilities to GAS infestation. Additionally, the study would incorporate choice studies to assess the consumption preference for common broad leaf weeds and root crops found in farming districts in Trinidad. The current study could enable the application of precision-based approaches in the crop protection efforts against the GAS.

2. Methodology

2.1. Study location

The study was conducted in a semi-enclosed type of shed at the Agricultural Technology and Innovation Park, The University of the West Indies, Orange Grove, Trinidad (10° 37' 37" N, 61° 22' 15" W).

2.2. Collection of snails and treatment preparation

One hundred and twenty adult snails each measuring 5 cm in length were collected from non-treated abandoned farming areas within the Orange Grove farming district (10° 37' 49" N, 61° 22' 18" W), Trinidad. The snails were divided into groups of three and placed into well-ventilated covered plastic snap-top chambers measuring 54 cm long x 39 cm wide and 27 cm high to acclimatise for 24 h. The base of the chamber was covered with 5 cm of a well-moistened commercial sphagnum peat moss (certified to be a minimum of 90%) for the purpose of simulating soil-like conditions for burrowing and maintaining relative humidity. Additionally, the peat moss assisted with absorbing snail excrements. The chambers were also misted with distilled water. During the acclimatisation period, the snails were fed ad libitum on a crop component which was not under investigation in an attempt to reset their palatability. Prior to the experiment, the snails were starved for 24 h to ensure that they would have been motivated to search for food by hunger (Scott, Dawson-Scully, & Sokolowski, 2005). Additionally, the snails were evaluated to ensure that no dead or moribund individuals were included in the various treatments.

2.3. Experimental design

The vegetative (leaves) and reproductive structures (flowers and pods/fruits) of ochro (*Abelmoschus esculentus*), pumpkin (*Cucurbita maxima*), seim (*Lablab purpureus*), papaya (*Carica papaya*) and eggplant (*Solanum melongena*) were used as well as the leaves of three root crops—cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*) and dasheen (*Colocasia esculenta*)—were used in the investigation. The crops were selected since they are popularly cultivated in Trinidad and Tobago. Additionally, the leaves from three (3) weeds commonly found in the farming district (*Amaranth spp*, *Portulaca oleracea* and *Cleome spp*) were included to determine if the GAS would consume them. The weeds were included to examine further the phytophagous nature of the GAS beyond the consumption of cultivated crops. All plant material was collected within 24 h and prepared 30 m before being offered to the GAS.

Ten (10) grams of leaves, flowers and pod/fruit from each crop (ochro, pumpkin, seim, papaya and melongene) were placed into standard-sized petri-dish. The various crop components (leaves flower and pods/fruits) were randomly placed into each chamber. The three (3) crop components for each crop were replicated five (5) times in five separate chambers each comprising three adult snails.

Ten (10) grams of the leaves from each root crop were each placed into a petri-dish and then introduced into each chamber with three snails; this was replicated five (5) times. Similarly, ten (10) grams of each weed was placed into a petri-dish and introduced into each chamber with three adults snails also with an average length of 5 cm, and this was also replicated five (5) times. The petri-dish with each plant material was positioned 5 cm apart from each other in the chamber.

The petri dishes for each planting material used in the study were positioned 5 cm from each other in the respective chambers and introduced to the snails at 5 p.m. since the snail are known to be active at night (Ademolu et al., 2011). A separate chamber without snails was used for each crop type used in the study to estimate and correct for evaporative losses.

2.4. Data collection

The unconsumed contents from each petri dish in all the replicates for each crop type were weighed using a digital top loading balance after a period of 24 h and 48 h. Prior to weighing the unconsumed contents, any exogenous material which may have included the commercial sphagnum peat moss and snail excrement was carefully removed. Water loss from

unconsumed plant material was corrected based on the estimated water loss from the control to provide an accurate as possible unconsumed weight. The amount of plant material consumed was obtained from the difference between the initial weight of the plant material used in the investigation and the estimated corrected unconsumed plant material. Before the petri dishes were returned to the chamber, the chambers were each completely misted with 15 ml of distilled water.

2.5. Data analysis

Analysis of Variance (ANOVA) was conducted using Statistical Package for Student of Social Sciences (SPSS) version 22. The significant differences in means ($p < .05$) were then identified using the Dunnett Post-Comparison Test.

3. Results

3.1. Agricultural crops—vegetative and reproductive structures (see Table 1)

In the first 24 h of the investigation, the results from the Analysis of Variance indicated that there were significant differences in the average quantity of the different plants consumed. The adjusted r square values ranged from a minimum of 0.74 for papaya to a maximum of 0.92 for pumpkin. All the F-ratios translated into a p-value of 0.00. After 48 h of the snails' exposure to the various treatments, the results from the Analysis of Variance indicated that there were significant differences in the average quantity of some of the different plants consumed. The average consumption of the various plant parts for okra and pumpkin were not statistically different at the 5% level. The adjusted r square values ranged from a minimum of 0.23 for pumpkin to a maximum of 0.79 for eggplant.

Table 1. Analysis of variance between the quantities of different crop parts consumed

Table 1. Analysis of variance between the quantities of different crop parts consumed					
Okra	After 24 h		Okra	After 48 h	
Source	F-Ratio	Sig.	Source	F-Ratio	Sig.
Corrected Model	26.15	0.00	Corrected Model	3.28	0.07
Intercept	145.95	0.00	Intercept	22.96	0.00
Parts	26.15	0.00	Parts	3.28	0.07
Adj.R square	0.78		Adj.R square	0.35	
(I) Parts (Means)	(J)Parts(Means)	M.D.	(I) Parts (Means)	(J)Parts(Means)	M.D.
Okra Pods (0.94)	Okra Leaves (7.96)	-7.02*	Okra Pods (0.46)	Okra Leaves (1.82)	-1.38
Okra Flowers (5.82)	Okra Leaves (7.96)	-2.14	Okra Flowers (2.52)	Okra Leaves (1.82)	0.70
Pumpkin	After 24 h		Pumpkin	After 48 h	
Source	F-Ratio	Sig.	Source	F-Ratio	Sig.
Corrected Model	86.09	0.00	Corrected Model	3.06	0.08
Intercept	740.29	0.00	Intercept	12.12	0.00
Parts	86.09	0.00	Parts	3.06	0.08
Adj. R square	0.92		Adj. R square	0.23	
(I) Parts (Means)	(J)Parts(Means)	M.D.	(I) Parts (Means)	(J)Parts(Means)	M.D.
Pumpkin fruits (10.00)	Pumpkin Leaves (8.08)	1.92*	Pumpkin Fruit (6.87)	Pumpkin Leaves (8.08)	-1.92
Pumpkin Flowers (2.29)	Pumpkin Leaves (8.08)	-5.79*	Pumpkin Flowers (3.88)	Pumpkin Leaves (8.08)	-0.19

(Continued)

Table 1. (Continued)

Egg Plant	After 24 h	Egg Plant	After 48 h		
Source	F-Ratio	Sig.	Source	F-Ratio	Sig.
Corrected Model	673.65	0.00	Corrected Model	27.18	0.00
Intercept	1337.65	0.00	Intercept	72.86	0.00
Parts	673.65	0.00	Parts	27.18	0.00
Adj.R square	0.99		Adj.R square	0.79	
(I) Parts (Means)	(J)Parts(Means)	M.D.	(I) Parts (Means)	(J)Parts(Means)	M.D.
Egg Plant Fruit (9.70)	Egg Plant Leaves (0.36)	9.34*	Egg Plant Fruit (0.30)	Egg Plant Leaves (0.77)	-0.47
Egg Plant Flowers (2.08)	Egg Plant Leaves (0.36)	1.72*	Egg Plant Flowers (2.95)	Egg Plant Leaves (0.77)	2.18*
Papaya	After 24 h	Papaya	After 48 h		
Source	F-Ratio	Sig.	Source	F-Ratio	Sig.
Corrected Model	21.01	0.00	Corrected Model	8.53	0.00
Intercept	106.67	0.00	Intercept	48.95	0.00
Parts	21.01	0.00	Parts	8.53	0.00
Adj.R square	0.74		Adj.R square	0.52	
(I) Parts (Means)	(J)Parts(Means)	M.D.	(I) Parts (Means)	(J)Parts(Means)	M.D.
Papaya Fruit (2.42)	Papaya leaves (8.59)	-6.17*	Papaya Fruit (6.87)	Papaya leaves (1.14)	5.73*
Papaya Flowers (2.64)	Papaya leaves (8.59)	-5.95*	Papaya Flowers (3.88)	Papaya leaves (1.14)	2.74
Seim	After 24 h	Seim			
Source	F-Ratio	Sig.	Source	F-Ratio	Sig.
Corrected Model	56.54	0.06	Corrected Model	55.50	0.00
Intercept	463.59	0.00	Intercept	174.15	0.00
Parts	56.54	0.06	Parts	55.50	0.01
Adj.R square	0.384		Adj.R square	0.566	
(I) Parts (Means)	(J)Parts(Means)	M.D.	(I) Parts (Means)	(J)Parts(Means)	M.D.
Seim Pods (6.70)	Seim leaves (2.83)	3.87	Seim Pods (1.46)	Seim leaves (6.03)	-4.57*
Seim Flowers (7.15)	Seim leaves (2.83)	4.33	Seim Flowers (2.74)	Seim leaves (6.03)	-3.29*

* significance at the 5% level, Dunnett Post-Comaparison test was used MD—Difference between means

The results of the Dunnett’s Post-Comparison Test indicated that there were significant differences in the average consumption of the different parts of the plants in the first 24 h. In the case of okra, there was a significant difference in the quantity of the okra pods consumed when compared with the quantity of okra leaves consumed. The negative mean difference of 7.02 for okra indicated that the snails showed a greater preference for the leaves over the pods.

For pumpkin, there was a significant difference in the quantity of pumpkin fruit and flowers consumed when compared with the quantity of pumpkin leaves consumed. The negative mean difference of 5.79 for pumpkin indicated that the snails showed a greater preference for the leaves over the pumpkin flowers. The positive mean difference of 1.92 for pumpkin indicated that the snails showed a greater preference for the fruit over the leaves.

In the case of eggplant, there was a significant difference in the quantity of eggplant fruit and flowers consumed when compared with the quantity of eggplant leaves consumed. The positive mean differences of 9.34 and 1.72 for eggplant indicated that the snails showed a greater preference for the fruit and flowers over the leaves.

With respect to papaya, there was a significant difference in the quantity of papaya fruit and flowers consumed when compared with the quantity of papaya leaves consumed. The negative mean differences of 6.17 and 5.95 for papaya indicated that the snails showed a greater preference for the leaves over the papaya fruit and flowers.

The positive mean difference of 3.87 and 4.33 for seim indicated that snails showed a greater preference for the pods and flowers over the leaves.

After 48 h, the results of the Dunnett's Post-Comparison Test indicated that there were significant differences in the average consumption of the different parts of the plants except for okra and pumpkin. The positive mean differences of 2.184 for eggplant indicated that the snails showed a greater preference for the flowers over the leaves. The positive mean differences of 5.728 for papaya indicated that the snails showed a greater preference for the fruit over the leaves. The negative mean differences of 4.57 and 3.29 for seim indicated that snails showed a greater preference for the leaves over the pods and flowers, respectively.

3.2. Selected root crops (vegetative structures) and selected broad leaf weeds (see Table 2)

The adjusted *r* square values ranged from a minimum of 0.79 to a maximum of 0.87 after 24 h for the leaves of the various crop types under investigation. After 48 h, the adjusted *r* square values ranged from a minimum of 0.47 to a maximum of 0.89.

In the first (24 h) and second day (48 h) of the trial, the results from the Analysis of Variance indicated that there were significant differences in the average quantity of the different leaves of the weeds and crops consumed. All the *F*-ratios translated into a *p*-value of 0.00.

The results of the Dunnett's Post-Comparison Test indicated that they were significantly different in the average consumption of the different leaves of the weeds and crops. In the case of the broadleaf weeds, there was significant difference in the quantity of leaves of the *Portulaca oleracea* consumed when compared with the quantity of *Cleome* spp. leaves consumed. In the case of the leaves of the root crops, there was significant difference in the quantity of sweet potatoes (*Ipomoea batatas*) leaves consumed when compared with the quantity of dasheen (*Colocasia esculenta*) leaves consumed. There was also significant difference in the quantity of sweet potatoes (*Ipomoea batatas*) leaves consumed when compared with the quantity of cassava (*Manihot esculenta*) leaves consumed.

In the first day, the positive mean difference of 1.82 for the broad leaf weeds indicated that the snails showed a greater preference for the *Portulaca oleracea* over the *Cleome* spp. The positive mean difference of 5.04 for the leaves of the crops indicated that the snails showed a greater preference for the leaves of sweet potatoes over the leaves of dasheen. The positive mean difference of 4.93 indicated that snails showed a greater preference for the sweet potatoes over cassava for the first 24 h.

In the second day, the positive mean differences of 1.68 for the broad leaf weeds indicated that the snails showed a greater preference for the *Portulaca oleracea* over the *Cleome* spp. The positive mean difference of 2.80 for the leaves of the roots crops indicated that the snails showed a greater preference for the leaves of sweet potatoes over the leaves of dasheen. In the second day, the negative mean differences of 2.07 for the broad leaf weeds indicated that the snails showed a greater preference for the *Cleome* spp over the leaves of *Amaranth* spp. The positive mean difference

Table 2. Analysis of variance between the quantities of leaves consumed for selected weeds and root crops

Broad Leaf Weeds	After 24 h		Source	After 48 h	
	F-Ratio	Sig.		F-Ratio	Sig.
Corrected Model	46.37	0.00	Corrected Model	57.28	0.00
Intercept	154.42	0.00	Intercept	183.39	0.00
Parts	46.37	0.00	Parts	57.28	0.00
Adj.R square	0.87		Adj.R square	0.89	
(I) Weeds (Means)	(J) Weeds	MD	(I) Weeds	(J) Weeds	MD
Portulaca Oleracea (4.43)	Cleome (2.61)	1.82*	Portulaca Oleracea (3.75)	Cleome (2.07)	1.68*
Amaranthus (0.00)	Cleome (2.61)	-2.61	Amaranthus (0.00)	Cleome (2.07)	-2.07*
Root Crop Leaves	Day 1		Root Crop Leaves	Day 2	
	F-Ratio	Sig.		F-Ratio	Sig.
Corrected Model	27.05	0.00	Corrected Model	7.11	0.00
Intercept	72.85	0.00	Intercept	43.00	0.00
Leaf Type	27.05	0.00	Leaf Type	7.11	0.01
Adj. R square	0.79		Adj. R square	0.47	
(I) Crops (Means)	(J) Crops (Means)	MD	(I) Crops (Means)	(J) Crops (Means)	MD
Sweet Potato (6.05)	Dasheen (1.01)	5.04*	Sweet Potato (3.95)	Dasheen (1.15)	2.80*
Cassava (1.12)	Dasheen (1.01)	0.11	Cassava (1.45)	Dasheen (1.15)	0.30
Sweet Potatoes (6.05)	Cassava (1.12)	4.93*	Sweet Potatoes (5.15)	Cassava (1.45)	3.70*

* significance at the 5% level, Dunnett Post-Comparisons test was used MD—Difference between means

of 3.70 indicated that snails showed a greater preference for the sweet potato leaves over cassava leaves pointing to the preference of sweet potato leaves over cassava over a period of 48 h.

4. Discussion and conclusion

GAS phytophagous feeding behaviour is detrimental to crop production and food security, particularly in countries with struggling agricultural economies. A thorough comprehension of the feeding behaviour in relation to crop types and the palatability preference for intraspecific crop parts can enable targeted crop protection strategies such as precision-based crop protection approaches. Since the central focus of pest populations and their control is driven by the interaction of the host, pest and the environment (Gisi & Leadbeater, 2010), establishing the specific vulnerabilities associated with the host risk is fundamental for controlling the impact of the pest. Factoring the specific preferential selectivity of plants structures, particularly the vegetative and reproductive structures within a crop type, is important to making the approach to controlling the giant African snail more designable. Although the giant African snail is a generalist in its feeding habit, the current study pointed to the intraspecific site vulnerabilities within economic crop plants. Although the giant African snail preference for food plants depends on the plant community composition and varies according to quality and quantity (Madjos & Demayo, 2017), the vulnerable parts of the plant must be taken into consideration in order to target specific crop protection efforts. Targeted crop protection will assist in reducing the probability and/or impact of the presence of the Giant African Snail to an acceptable threshold. In the ochro plants, for instance, the leaves are more vulnerable to the Giant African Snail when compared to the other structures. Since the leaves of the ochro plant are

more vulnerable to the GAS, then protecting the leaves by using antifeedants or repellents can be a priority in the cultivation of ochro plants in GAS-infested areas.

The issue of neglected and uncontrolled weed biodiversity in an agricultural landscape provides a potential feed source for the Giant African Snail in the absence of a cultivated crop (Chandaragi, 2014). The type of weed and the abundance of preferentially palatable type of weeds can influence the GAS populations. Since the GAS can reach high densities and biomass in a very short time (Raut & Barker, 2002; Raut & Ghose, 1984), reducing the potentially favourable weed food sources can possibly influence the rate of biomass accumulation leading to faster sexual maturity attainment. The current study provided evidence that there was preferential selectivity for the weed options offered to the GAS. *Portulaca oleracea* was preferred over *Cleome* spp, and *Cleome* spp was preferred over the leaves of *Amaranth* spp. Although *Amaranth* is least preferred, it is not excluded from the GAS diet as has been reported by Smith and Fowler (2003) and Raut and Barker (2002). The vegetative components of the selected roots crops are also vulnerable to the GAS. Although this study shows that the leaves of the sweet potato were preferred over the leaves of dasheen, dasheen is also a known food source for the GAS (Madjos & Demayo, 2017). In dasheen monocultures, the GAS would be able to consume the leaves as a source of food; the foraging volume consumed, however, may be less than that in sweet potato cropping systems. The GAS population densities in sweet potato when compared to dasheen may be expected to be much higher considering the apparent palatability preference for sweet potato and the implications related to biomass accumulation and sexual maturity attainment.

The current study concludes that although the Giant African Snail is phytophagous, there are intra-specific preferences for the parts of plant. This knowledge is useful to design more appropriate and targeted crop protection efforts. Given the broad spectrum of food choices for the Giant African Snail in multi-cropping agricultural production zones, knowing the vulnerable plant parts on a plant as well as the preference for one plant over another can influence where additional attention in the management of the GAS is necessary. The preferences for weed species as a preferred food source for the GAS must also be factored into the management plan if more preferred weeds as food sources exist in the crop production system. Although it is important to reduce the population pressure of the GAS in the cropping system, understanding the specific vulnerabilities of the crop to the preferential herbivory by the GAS is important, and this has implications for the success of the crop protection efforts.

Competing interests

The authors declare no competing interests.

Author details

Marcus Ramdwar¹
E-mail: marcusramdwar@gmail.com
ORCID ID: <http://orcid.org/0000-0002-2175-3680>
Wayne Ganpat²
E-mail: Wayne.Ganpat@sta.uwi.edu
Jesse Harripersad¹
E-mail: jesse.harripersad@yahoo.com
Wendy Isaac³
E-mail: Wendy-Ann.Isaac@sta.uwi.edu
Donald Palmer⁴
E-mail: palmerdon2002@yahoo.com
¹ Agriculture Biosciences Agriculture and Food Technologies, University of Trinidad and Tobago, ECIAF Campus, Caroni North Bank Road, Centeno, Arima, Trinidad.
² Dean, Faculty of Food and Agriculture The University of the West Indies, St. Augustine Campus.
³ Department of Food Production Faculty of Food and Agriculture The University of the West Indies, St. Augustine, Trinidad, West Indies.

⁴ Department of Agricultural Economics and Extension Faculty of Food and Agriculture The University of the West Indies, St. Augustine, Trinidad, West Indies.

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