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Morphometric characterization of invasive *Diaphorina citri* infesting citrus and orange jasmine in Ghana

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ABSTRACT

Morphometric analysis plays a crucial role in the accurate identification and classification of insect pests, which is essential for implementing effective management strategies. The Asian citrus psyllid (*Diaphorina citri* Kuwayama; Hemiptera: Liviidae), an invasive species and a known vector of ‘*Candidatus Liberibacter asiaticus*’ and ‘*Ca. Liberibacter americanus*’, the bacterial pathogens associated with Huanglongbing (HLB), has recently emerged as a pest of concern in Ghana. Despite its significance, little is known about the biological traits of field populations in the region. In this study, we examined morphometric variation in *D. citri* populations infesting citrus and orange jasmine (*Murraya paniculata*) across different regions, agroecological zones, and host plants in Ghana. Our results show that several morphometric traits varied significantly by region, agroecological zone, and host plant. These findings suggest that host plant species and environmental conditions may influence the morphological traits of ACP, potentially affecting its dispersal and adaptability. Importantly, this study also documents the infestation of citrus orchards in Ghana by *D. citri*, following its initial detection on ornamental plants. This highlights a critical and urgent threat to Ghana’s citrus industry and the need for coordinated surveillance and management efforts to prevent the establishment and spread of HLB in the region.

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Introduction

Phenotypic expression in organisms is dynamic, changing throughout individual development and across generations through evolutionary processes (Csósz et al., 2021). Morphometric analysis, an approach that quantifies variations in body size, shape, and structural ratios, is a powerful tool for detecting such changes and understanding how environmental and biological factors shape phenotypic diversity (Daly, 1985). This technique has proven especially useful in entomological studies, where subtle morphological differences can reveal adaptations to local conditions, environmental gradients, or geographic separation (Aidoo et al., 2019; Tetey et al., 2022).

Traditional morphometric methods, which often include measurements of body length, width, and wing geometry (e.g. venation patterns and aspect ratios), are widely used to differentiate insect species and characterize intraspecific variability (Paris et al., 2016; Aidoo et al., 2019). For instance, morphometric traits such as body and wing dimensions have been used to study *Bactericera cockerelli* (Šulc)

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(Vargas-Madríz et al., 2013) and *Diaphorina citri* (Kuwayama), the Asian citrus psyllid (ACP), in various geographic contexts (García-Pérez et al., 2013; Lashkari et al., 2015).

ACP is the primary vector of '*Candidatus Liberibacter asiaticus*' (CLas) and '*Ca. Liberibacter americanus*' (CLam), the phloem-limited bacteria that cause huanglongbing (HLB), one of the most destructive diseases of citrus globally (Bové, 2014; Grafton-Cardwell et al., 2013). Due to its high reproductive rate, broad host range within the Rutaceae family, and capacity for long-distance dispersal, ACP has established itself across nearly all major citrus-producing regions (Aidoo et al., 2022). In 2023, ACP was reported for the first time in Ghana, on ornamental *Murraya paniculata* ((L.) Jack) in the Volta Region (Aidoo et al., 2023). This discovery raises major concerns for Ghana's citrus industry, given the country's favorable climatic conditions for both ACP and *Ca. Liberibacter* spp. (Narouei-Khandan et al., 2016; Souza et al., 2024).

Host plant species and geographic location have been shown to significantly influence the morphology of various insect pests, including *Trioza erytreae* (Aidoo et al., 2019), *Oryctes monoceros* (Tettey et al., 2022), *Aeolothrips intermedius* (Gruss et al., 2019), and *B. cockerelli* (Mustafa et al., 2015). In *D. citri*, field-collected adults have displayed notable morphometric variation across different host plants and environmental conditions (García-Pérez et al., 2013; Lashkari et al., 2015). However, the relative contributions of biotic (e.g. host plant) and abiotic (e.g. climate and elevation) factors to these differences remain unclear.

A clearer understanding of morphometric variability in ACP is vital for accurate identification, tracking of invasion dynamics, and the development of targeted control measures. This study aimed to characterize the morphometric traits of field-collected ACP populations in Ghana and to assess how the traits vary by host plant, regions, and agroecological zone. We hypothesized that: (1) ACP morphometric traits would differ between host plants, (2) sampling regions would significantly influence morphological traits, and (3) agroecological zones would affect ACP phenotype. Our results confirmed significant variation in ACP morphology across these factors, offering new insights into the biology and dispersal potential of this invasive pest. These findings can inform future surveillance and management strategies to mitigate the threat posed by ACP in Ghana and beyond.

2. Materials and methods

2.1. Species collection and sample handling

Adult *Diaphorina citri* (ACP) specimens were collected from citrus and *Murraya paniculata* (orange jasmine) plants across three regions in Ghana: Eastern, Greater Accra, and Volta. A total of 94 adult females were randomly selected for morphometric analysis. Each specimen was stored individually in 1.5 mL microcentrifuge tubes containing 70% ethanol and transported to the laboratory for further processing.

Only adult females were included in the analysis, consistent with prior studies indicating that species-level identification in ACP relies heavily on female-specific and non-genitalic morphological features (Lashkari et al., 2015; Paris et al., 2016). In the laboratory, each specimen was dissected under a stereomicroscope, and key anatomical structures were isolated for detailed measurement.

2.2. Sample preparation and morphological measurements

Fourteen standard morphometric traits were selected based on previous literature (Lashkari et al., 2015; Paris et al., 2016) and are illustrated in Figure 1. The measured structures were mounted on glycerin slides using Euparal as the mounting medium. The right forewing and right hind leg were considered for consistency across all specimens. Measurements were taken at 25× magnification using a Leica EZ4 stereomicroscope equipped with an integrated CMOS camera. Morphometric data were recorded in millimeters using Leica Application Suite software (Version 3.4.0: Build 272).

2.3. Data analysis

All statistical analyses were conducted using R software (version 4.3.3; R Core Team, 2024), with a significance level set at $p < 0.05$. Homogeneity of variance was assessed prior to conducting analysis. To assess overall morphological differences, a multivariate analysis of variance (MANOVA) was used to compare group means across regions, host plants, and agroecological zones. For individual morphometric traits,

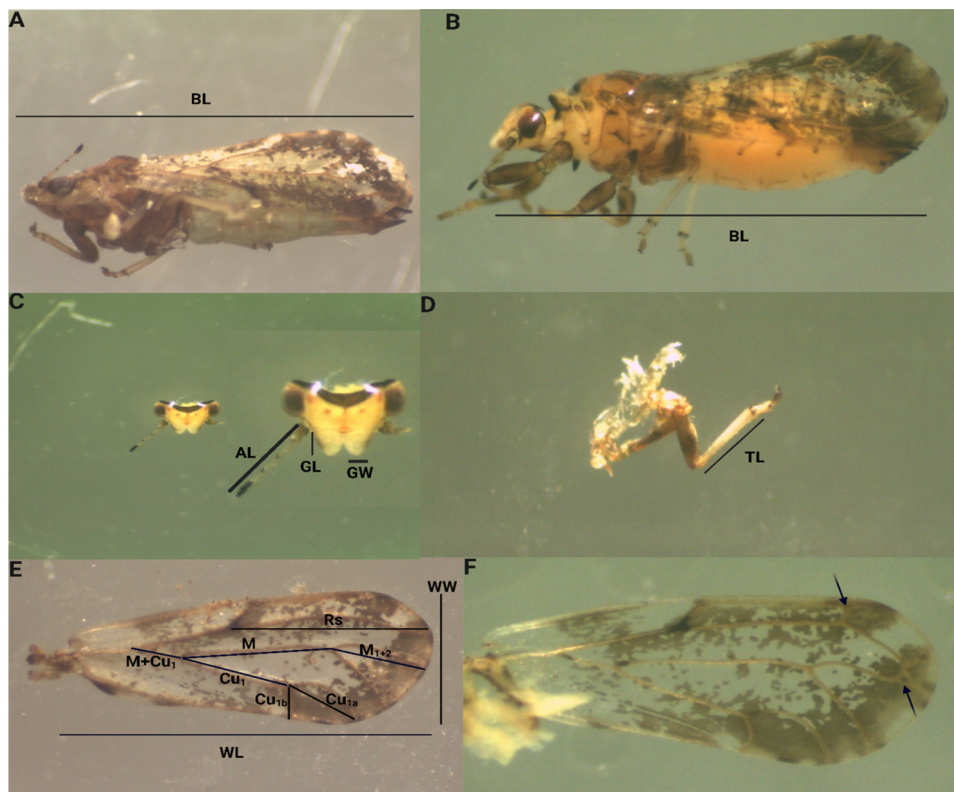


Figure 1. Morphometric traits measured in *Diaphorina citri* specimens from Ghana. (A-B) Body length; (C) antenna length (AL), genal length (GL), and genal width (GW); (D) tibia length; (E) wing measurements including wing length (WL), wing width (WW), and wing veins: M, Cu₁, Cu_{1a}, Cu_{1b}, Rs, M+Cu₁, and M₁₊₂.

Kruskal-Wallis test was applied. Where significant differences were observed, the means were separated using Dunn's post-hoc test with Bonferroni correction. To compare ACP populations from different agroecological zones, morphometric data were $\log_{10}(x+1)$ -transformed prior to statistical analysis; however, untransformed means are presented in the results tables. Next, we used either Student's *t*-test or Welch's *t*-test, depending on whether the assumption of equal variances was met. Hierarchical clustering was performed using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA), following Sneath (1979), with squared Euclidean distances as the similarity metric. Derived morphological indices included wing aspect ratio (calculated as wing length divided by wing width) and wing loading (tibia length divided by wing length), following Paris et al. (2016).

3. Results

Multivariate analysis of variance (MANOVA) showed significant effects of region, sampling site, agroecological zone, and host plant on the morphometric traits of *Diaphorina citri* (ACP) populations. Specifically, the multivariate effects were significant for region (Pillai's Trace = 0.9157, approx. $F=4.064$, $df = 32, 154$, $p<0.001$), agroecological zone (Pillai's Trace = 0.5223, approx. $F=5.2626$, $df = 16, 77$, $p<0.001$), and host plant (Pillai's Trace = 0.5648, approx. $F=1.8936$, $df = 32, 154$, $p=0.005$).

Univariate analyses revealed that most morphometric traits significantly varied by region, except for tibia length ($\chi^2 = 1.081$, $df = 2$, $p=0.582$), wing width ($\chi^2 = 0.295$, $df = 2$, $p=0.862$), genal length ($\chi^2=2.278$, $df = 2$, $p=0.320$), antenna length ($\chi^2 = 0.070$, $df = 2$, $p=0.965$), Cu_{1b} ($\chi^2 = 2.038$, $df = 2$, $p=0.360$), and Rs vein length of forewing ($\chi^2 =1.250$, $df = 2$, $p=0.535$) (Table 1). Significant differences among agroecological zones were observed for body length, genal width, M+Cu₁, M, and M₁₊₂ (Table 2). Host plant comparisons revealed significant variation in wing length, tibia length, Cu₁, M, and Cu_{1a} (Table 3).

Ordination analysis based on agroecological zones showed some overlap in ACP morphotypes but also highlighted distinct groupings. Hierarchical cluster analysis indicated that ACP individuals collected

Table 1. Size of morphological traits (mean \pm standard error) (mm) of female *Diaphorina citri* from different regions.

Traits	Eastern	Greater accra	Volta	χ^2	df	P-value
Body length	2.48 \pm 0.04a	2.79 \pm 0.02ab	2.79 \pm 0.04b	32.350	2	<0.001
Wing length	2.19 \pm 0.01ab	2.20 \pm 0.01a	2.15 \pm 0.02b	6.752	2	0.034
Wing Width	0.88 \pm 0.18a	0.88 \pm 0.01a	0.88 \pm 0.12a	0.295	2	0.862
Tibia length	0.53 \pm 0.02a	0.55 \pm 0.01a	0.55 \pm 0.01a	1.081	2	0.582
Genal length	0.13 \pm 0.00a	0.13 \pm 0.00a	0.12 \pm 0.00a	2.278	2	0.320
Genal width	0.17 \pm 0.05a	0.13 \pm 0.00ab	0.09 \pm 0.00b	6.962	2	0.030
Antenna length	0.39 \pm 0.01a	0.37 \pm 0.01a	0.37 \pm 0.01a	0.070	2	0.965
M + Cu ₁	0.27 \pm 0.00a	0.27 \pm 0.00a	0.25 \pm 0.00b	9.066	2	0.010
M	0.87 \pm 0.02ab	0.90 \pm 0.01a	0.87 \pm 0.01b	9.511	2	0.008
Cu ₁	0.65 \pm 0.02a	0.68 \pm 0.01a	0.64 \pm 0.01b	10.825	2	0.004
Cu _{1b}	0.18 \pm 0.00a	0.19 \pm 0.01a	0.17 \pm 0.00a	2.038	2	0.360
Cu _{1a}	0.44 \pm 0.01ab	0.46 \pm 0.01a	0.43 \pm 0.01b	8.052	2	0.017
M ₁₊₂	0.58 \pm 0.01a	0.56 \pm 0.01ab	0.54 \pm 0.01c	15.958	2	<0.001
Rs	0.17 \pm 0.01a	0.19 \pm 0.01a	0.16 \pm 0.01a	1.250	2	0.535

Note: *Means with different letters within a row are significantly different ($\alpha < 0.05$) (Dunn's post-hoc test with Bonferroni correction) between regions.

Table 2. Size of morphological traits (mean \pm standard error) (mm) of female *Diaphorina citri* from different agroecological zones.

Traits/location	Coastal	Deciduous	t-Value	df	p-value
Body length	2.79 \pm 0.02a	2.48 \pm 0.04b	7.39	92	<0.001
Wing length	2.18 \pm 0.01a	2.19 \pm 0.01a	-0.28	92	0.779
Wing width	0.88 \pm 0.00a	0.88 \pm 0.01a	-0.21	92	0.818
Tibia length	0.55 \pm 0.00a	0.53 \pm 0.02a	1.45	92	0.149
Genal length	0.13 \pm 0.00a	0.13 \pm 0.00a	-0.26	92	0.798
Genal width	0.10 \pm 0.00a	0.17 \pm 0.05b	-2.84	92	0.005
Antenna length	0.37 \pm 0.00a	0.39 \pm 0.01a	-1.14	92	0.258
M + Cu ₁	0.26 \pm 0.00a	0.27 \pm 0.00b	-2.03	92	0.045
M	0.89 \pm 0.01a	0.87 \pm 0.02b	2.26	92	0.026
Cu ₁	0.67 \pm 0.00a	0.65 \pm 0.02a	0.98	92	0.326
Cu _{1b}	0.18 \pm 0.01a	0.19 \pm 0.00a	0.47	92	0.637
Cu _{1a}	0.45 \pm 0.01a	0.44 \pm 0.01a	1.00	92	0.318
M ₁₊₂	0.55 \pm 0.00a	0.58 \pm 0.01b	-2.89	92	0.005
Rs	1.18 \pm 0.01a	1.17 \pm 0.01a	0.28	92	0.775

Note: *Means with different letters within a row are significantly different ($\alpha < 0.05$) (t-test) between agroecological zones.

Table 3. Size of morphological traits (mean \pm standard error) (mm) of female *Diaphorina citri* from different host plants.

Traits	<i>Citrus limon</i>	<i>Citrus sinensis</i>	<i>Murraya paniculata</i>	χ^2	df	p-Value
Body length	2.76 \pm 0.03a	2.76 \pm 0.04a	2.67 \pm 0.03a	2.850	2	0.240
Wing length	2.20 \pm 0.02ab	2.23 \pm 0.02b	2.17 \pm 0.01a	10.096	2	0.006
Wing width	0.89 \pm 0.01a	0.89 \pm 0.01a	0.88 \pm 0.00a	5.614	2	0.060
Tibia length	0.53 \pm 0.01a	0.56 \pm 0.01b	0.54 \pm 0.01a	6.719	2	0.034
Genal length	0.13 \pm 0.01a	0.13 \pm 0.00b	0.13 \pm 0.00a	0.534	2	0.765
Genal width	0.11 \pm 0.00a	0.10 \pm 0.00a	0.13 \pm 0.02a	3.283	2	0.193
Antenna length	0.38 \pm 0.01a	0.39 \pm 0.01a	0.38 \pm 0.01a	1.131	2	0.567
M + Cu ₁	0.27 \pm 0.01a	0.27 \pm 0.01a	0.26 \pm 0.00a	2.131	2	0.344
M	0.92 \pm 0.01ab	0.91 \pm 0.01bd	0.87 \pm 0.01ac	16.760	2	<0.001
Cu ₁	0.68 \pm 0.01ab	0.69 \pm 0.01b	0.65 \pm 0.01a	10.963	2	0.004
Cu _{1b}	0.22 \pm 0.04a	0.18 \pm 0.00a	0.17 \pm 0.00a	2.911	2	0.233
Cu _{1a}	0.46 \pm 0.01ab	0.47 \pm 0.01bc	0.43 \pm 0.00ac	15.322	2	<0.001
M ₁₊₂	0.55 \pm 0.01a	0.58 \pm 0.01a	0.55 \pm 0.00a	5.9378	2	0.051
Rs	1.18 \pm 0.02a	1.19 \pm 0.02a	1.17 \pm 0.02a	3.435	2	0.179

Note: *Means with different letters within a row are significantly different ($\alpha < 0.05$) (Dunn's post-hoc test with Bonferroni correction) among plants.

from *Citrus sinensis* and *C. limon* were more like each other than those from *Murraya paniculata*, which formed a distinct cluster (Figure 2).

Regional comparisons also demonstrated clear morphological differentiation. Although some overlap was evident, ordination plots (Figure 3) showed distinct separation among ACP populations from the Eastern, Greater Accra, and Volta regions. The dendrogram supported this result, indicating greater morphological similarity between populations from Greater Accra and Volta than those from the Eastern region. Analysis of wing aspect ratio and wing loading (Figure 4) revealed that wing aspect ratio differed

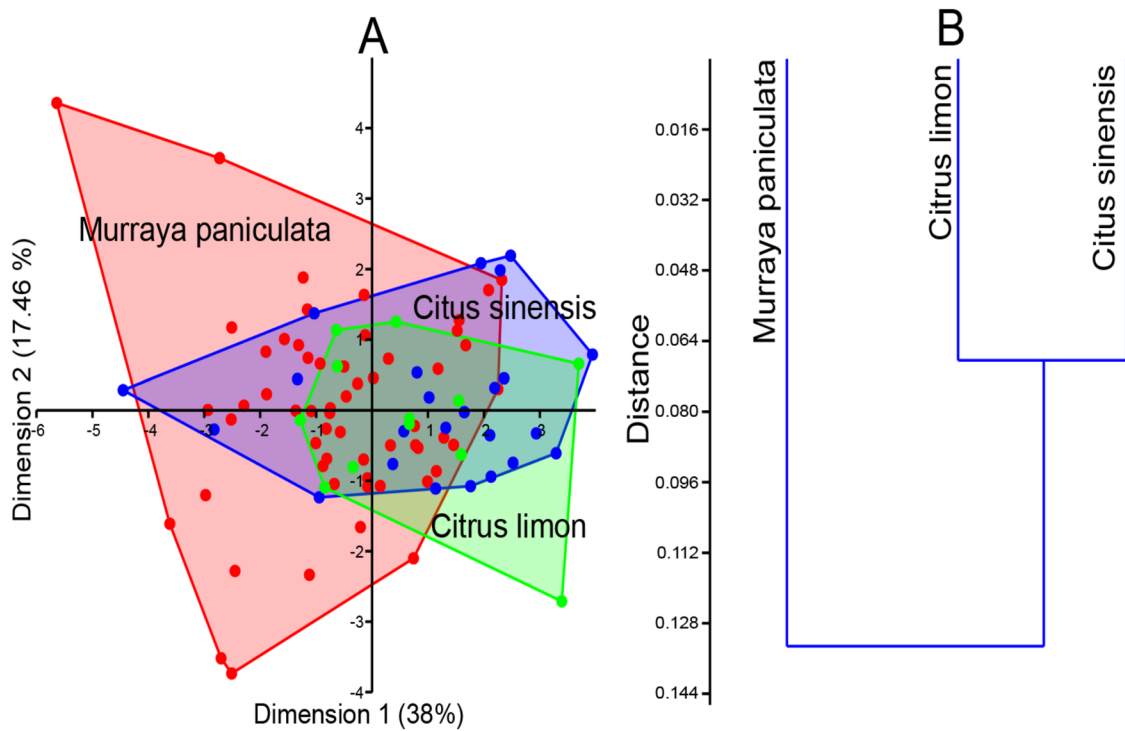


Figure 2. Ordination Plot (A) and Dendrogram (B) illustrating the morphometric relationships across different host plants (*Murraya paniculata*, *Citrus sinensis*, and *Citrus limon*) in Ghana.

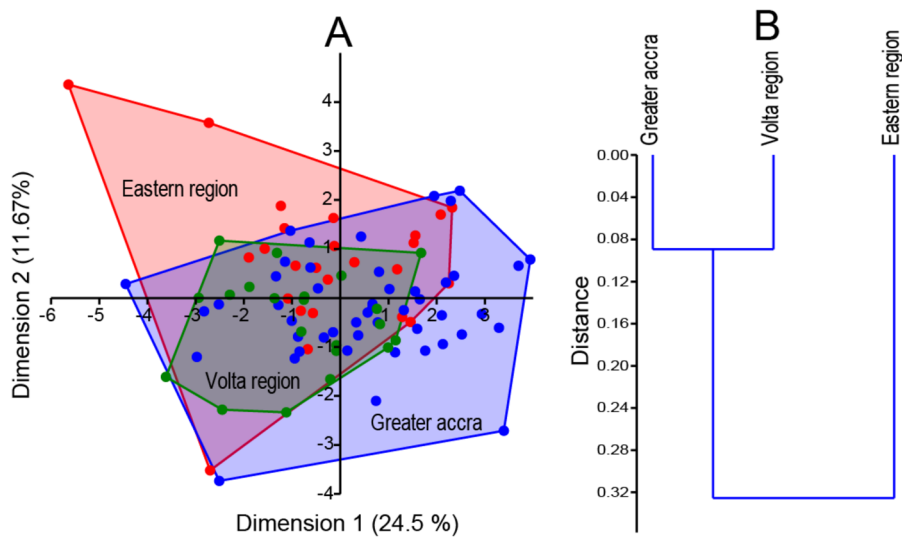


Figure 3. Ordination Plot (A) and Dendrogram (B) depicting the morphometric relationships among *Diaphorina citri* populations from different regions in Ghana.

significantly across regions ($\chi^2 = 9.690$, $df = 7$, $p = 0.007$), but not across host plants and agroecological zones. Additionally, wing loading showed no significant differences across regions, agroecological zones and host plants.

Principal component analysis (PCA) (Table 4) identified the primary traits contributing to morphological variation. The first principal component (PC1) was largely influenced by wing length, wing width, body length, and the lengths of key wing veins (M_{1+2} , M , Cu_{1ar} and Rs). The second principal component (PC2) was driven by high positive loadings for antenna length (0.47), $M + Cu_1$ (0.44), body length, genal length, and M_{1+2} . These traits collectively explain a substantial proportion of the observed variation among ACP populations.

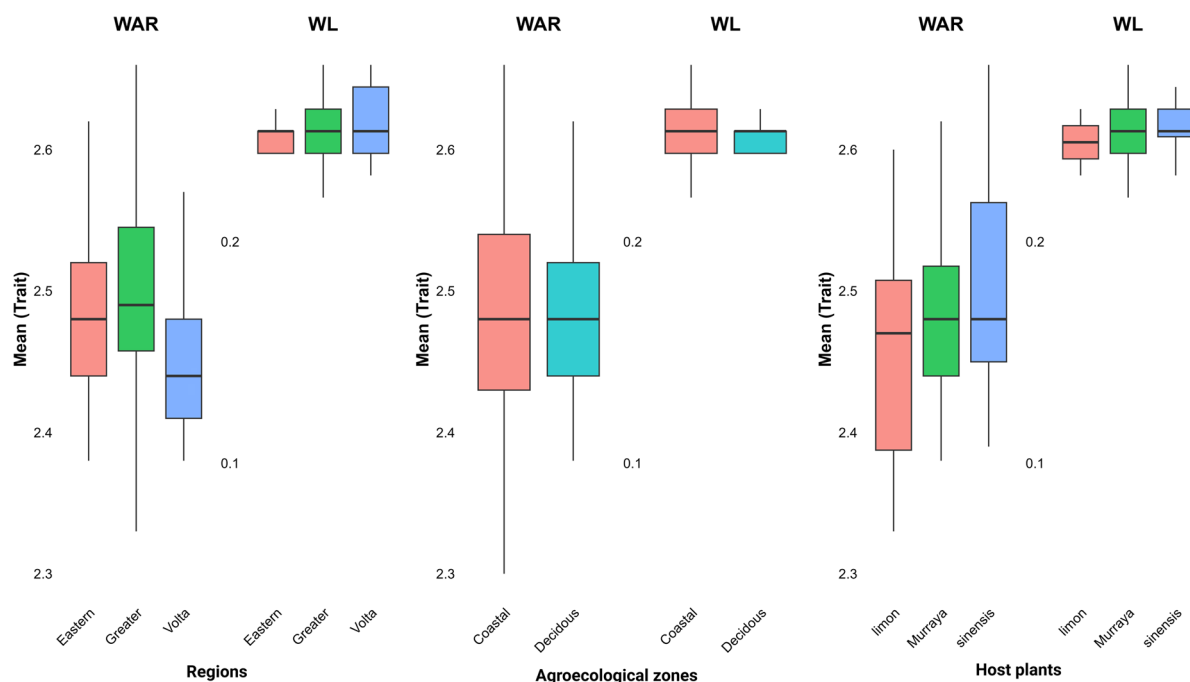


Figure 4. Box plot of morphometric traits across different *Diaphorina citri* populations. A) Wing aspect ratio (WAR) (wing length/wing width), and B) WL (wing loading) (tibia length/wing length) based on regions, agroecological zones and host plants in Ghana.

Table 4. Standardized coefficients of the first 14 principal components.

Trait	PC1	PC1	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14
Body length	0.23	-0.34	-0.26	0.28	-0.09	-0.24	-0.06	-0.44	0.28	0.18	0.54	0.03	0.17	0.05
Wing length	0.48	0.13	0.07	-0.03	0.05	-0.07	0.06	-0.05	0.16	0.06	-0.10	0.17	-0.27	-0.77
Wing width	0.47	0.03	0.12	0.02	0.00	-0.13	0.01	0.02	0.20	-0.04	-0.10	-0.43	-0.54	0.47
Tibia Length	0.03	0.04	-0.28	0.20	0.79	-0.18	0.33	0.00	-0.18	-0.03	-0.06	-0.23	0.12	-0.03
Genal length	0.06	-0.33	0.01	-0.55	0.21	0.07	0.09	0.54	0.23	0.21	0.38	0.00	0.02	-0.01
Genal width	-0.06	-0.15	0.64	0.10	0.22	-0.24	0.26	-0.11	0.18	0.15	-0.16	0.48	0.04	0.22
Antennae length	-0.02	0.47	0.12	0.44	-0.13	0.02	0.12	0.36	-0.10	0.54	0.32	-0.06	-0.02	0.01
M + Cu ₁	0.05	0.44	-0.02	-0.24	0.38	0.48	-0.27	-0.38	0.17	0.16	0.15	0.20	-0.05	0.19
M	0.38	-0.18	-0.15	0.00	-0.01	0.03	-0.33	0.11	-0.10	0.50	-0.52	0.03	0.38	0.12
Cu ₁	0.29	0.24	-0.44	-0.06	-0.15	-0.15	0.25	0.21	-0.07	-0.23	0.01	0.60	-0.01	0.30
Cu _{1b}	0.17	-0.18	0.03	0.42	0.00	0.65	0.23	0.18	0.36	-0.27	-0.08	-0.01	0.19	0.01
Cu _{1a}	0.26	-0.15	0.26	0.24	0.23	0.01	-0.53	0.21	-0.43	-0.32	0.29	0.18	-0.04	0.01
M ₁₊₂	0.30	0.37	0.32	-0.23	-0.09	-0.19	0.07	-0.03	0.07	-0.27	0.12	-0.27	0.63	0.01
Rs	0.26	-0.21	0.14	-0.18	-0.15	0.33	0.46	-0.29	-0.61	0.15	0.13	-0.04	-0.04	0.04

4. Discussion

This study provides the first confirmed record of ACP infesting citrus trees in Ghana, marking a significant development in the regional spread of this invasive pest in West Africa. While a prior report documented ACP presence on *M. paniculata* in the Volta Region (Aidoo et al., 2023), our findings establish that ACP has now successfully colonized its primary economic host, citrus, showing the pest's adaptability and growing threat.

As the known vector of CLas and CLam, the bacteria associated with huanglongbing (HLB or citrus greening disease), the presence of ACP on citrus poses a substantial risk to Ghana's citrus industry. Given that vector size and morphology can influence transmission efficiency and susceptibility to control measures (Lashkari et al., 2015), understanding ACP morphometrics is critical for the development of targeted surveillance and management strategies.

ACP was detected in multiple regions across Ghana, specifically the Volta, Eastern, and Greater Accra regions, highlighting its rapid dispersal and establishment. This distribution pattern mirrors global trends where ACP has spread widely from its native Asia to the Americas and parts of Africa (Aidoo et al., 2023; Oke et al., 2020; Sétamou et al., 2023) and reflects its strong invasive potential.

Morphometric comparisons revealed significant differences among ACP populations across host plants and agroecological zones. ACP individuals collected from *Citrus sinensis* and *C. limon* exhibited larger body sizes than those from *M. paniculata*, likely reflecting superior nutritional quality of citrus species during nymphal development. Citrus hosts are known to support larger ACP populations due to higher resource availability, in contrast to *M. paniculata*, which, despite producing frequent new flushes suitable for oviposition, may provide lower nutritional value (Paris et al., 2016). These findings align with previous reports of host-dependent size variation in ACP and support the idea that management of ornamental *M. paniculata* near citrus orchards may reduce ACP pressure.

Morphometric differences across agroecological zones further support the role of environmental factors in shaping ACP phenotypes. For example, ACP populations from the Coastal and Semi-Deciduous zones showed notable variation, consistent with phenotypic plasticity in response to local climatic conditions (Fusco & Minelli, 2010). Studies have shown that wing shape and size in ACP can vary with temperature, rainfall, and photoperiod, traits that may influence dispersal capacity and ecological adaptation (Paris et al., 2017). The Coastal Savannah and Semi-Deciduous zones receive approximately 1,200 mm and 600 mm of annual rainfall, respectively (Issaka et al., 2012), conditions that may differentially influence ACP morphometrics, as also reported by Tettey et al. (2022).

The observed morphometric variations among ACP populations may have important implications for their efficiency as vectors of HLB and their susceptibility to pest control strategies. Larger body sizes and stable wing structures in different populations may enhance CLas transmission, while narrower genal widths in the regions and host plants could limit feeding success. These findings underscore the need for region-specific and host species management strategies, such as targeting high-risk morphotypes or leveraging host plant resistance to counteract ACP adaptations. These differences also suggest the potential need for zone-specific management approaches. The coexistence of overlapping traits across agroecological zones, alongside distinct zone-specific characteristics, points to a complex ecological dynamic that may influence ACP dispersal capacity and population structure. Therefore, effective mitigation of ACP's impact on citrus production in Ghana will require targeted monitoring and adaptive management strategies that account for both morphological and ecological variability.

Our morphometric analyses identified wing length, wing width, body length, and specific forewing veins (M_{1+2} , M, Cu_1 , Cu_{1a} , and Rs) as the primary contributors to population-level variation. Although additional traits also varied, their influence was comparatively limited. These findings are consistent with those of Lashkari et al. (2015), who reported that body length and Rs vein length among the most discriminative traits within ACP populations from Iran, the USA, and Pakistan. Similarly, Paris et al. (2016), through canonical analysis, highlighted Cu_1 , M, M_{1+2} , and Rs vein lengths among the key contributors to morphological variation in laboratory-reared ACP.

In our study, ACP individuals from *M. paniculata* exhibited mean wing length, wing width, and tibia length of 2.17 mm, 0.88 mm, and 0.54 mm, respectively. In contrast, Paris et al. (2016), measured 2.04 mm (wing length), 0.83 mm (wing width), and 0.42 mm (tibia length) for ACP populations reared under laboratory conditions. The mean body length in our study was 2.70 mm on *C. sinensis*, slightly higher than those reported by Lashkari et al. (2015) for ACP populations in Chabahar and Jiroft (Iran) (2.45–2.47 mm), and Pakistan (1.98 mm). Also, ACP samples from several locations in Florida (Palm Beach, and St. Lucie Counties) had body length ranging from 2.53 to 2.57 mm (Lashkari et al. 2015).

Additional morphological comparisons revealed further similarities and differences. For example, Paris et al. (2016) recorded genal width of 0.11 mm, respectively, under laboratory conditions on *M. paniculata* whereas we measured a mean of 0.13 mm for the trait. In terms of wing venation, our values for $M+Cu_1$ (0.26 mm), Cu_{1b} (0.17 mm), Cu_{1a} (0.43 mm), and M_{1+2} (0.55 mm), are largely consistent with the values reported by Paris et al. (2016): 0.26 mm ($M+Cu_1$), 0.16 mm (Cu_{1b}), 0.45 mm (Cu_{1a}), and 0.56 mm (M_{1+2}). Notably, both studies reported identical Rs, M and Cu_1 veins length of 1.17, 0.87, and 0.66 mm, respectively. Minor discrepancies in trait measurements are likely due to environmental differences, such as temperature, humidity, and precipitation, during development (Paris et al., 2017).

5. Conclusion

This study highlights the influence of both biotic (host plant) and abiotic (agroecological zone) factors on the morphometric variation of ACP in Ghana. The confirmation of ACP on citrus marks a critical point in the establishment of the pest and potential threat to the country's citrus industry. The observed phenotypic diversity underscores the need for adaptive, zone-specific surveillance and management strategies. Further research is needed to determine how these phenotypic variations affect ACP fitness, vector competence, and response to control measures.

Disclosure statement

The authors declare no financial or personal conflicts of interest that could have influenced the outcomes or interpretations of this study.

Author contributions

CRedit: **Kodwo Dadzie Ninsin**: Conceptualization, Data curation, Supervision, Validation, Writing – original draft, Writing – review & editing; **Maxwell Kelvin Billah**: Writing – original draft, Writing – review & editing; **Bernard Agyeman Boateng**: Writing – original draft, Writing – review & editing; **Jonathan Osei-Owusu**: Conceptualization, Investigation, Supervision, Writing – original draft; **Fred Kormla Ablormeti**: Writing – review & editing; **Samuel Opuni-Basoa**: Formal analysis, Software, Validation, Visualization; **Aboagye Kwarteng Dofuor**: Writing – review & editing; **George Edusei**: Writing – review & editing; **Steve B. S. Baleba**: Data curation, Formal analysis, Investigation; **Owusu Fordjour Aidoo**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Data availability statement

All data generated or analyzed during the study are included in this manuscript. The data that support the findings of this study are available from the corresponding author upon reasonable request.

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