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Research Article

Stability of Sources of Resistance to Cowpea Aphid (*Aphis craccivora* Koch, Hemiptera: Aphididae) across Major Cowpea Production Zones in Ghana

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Aphids (*Aphis craccivora* Koch) are an important vegetative stage pest of cowpea in Africa. The use of resistant cultivars is among the best management option for this pest, but the success of this strategy is influenced by the stability of the resistant genotype to the cowpea aphid biotypes present in the major cowpea growing areas in a country. This work, therefore, aimed at identifying cultivars/genotypes with stable resistance to aphid infestation across different cowpea growing ecologies in Ghana and estimating yield loss due to aphid infestation at the seedling stage. To ascertain the stability of aphid-resistant cultivars/genotypes, four cultivars/genotypes (SARC1-57-2, SARC1-91-1, IT97K-499-35, and Zaayura) and a susceptible check (Apagbaala) were tested across 18 locations in Ghana. An on-station experiment was used to quantify yield losses due to aphid attack at the seedling stage in the five cultivars/genotypes mentioned above together with 5 additional cultivars/genotypes [i.e., IT99K-573-3-2-1, IT99K-573-1-1, Padituya, Resistant BC_4F_3 (Zaayura//(Zaayura × SARC1-57-2)), and Susceptible BC_4F_3 (Zaayura//(Zaayura × SARC1-57-2))]. The results showed that SARC1-57-2 was stable in all ecologies, in terms of its resistance to aphids; it had high vigour score (3.8 ± 0.03) and low plant mortality ($3.7 \pm 0.22\%$) compared to the susceptible genotypes. The number of days to flowering and maturity were significantly higher in aphid-infested plants than in the uninfested ones. Grain yield loss was estimated to range between 3.8 and 32.8%. Except for SARC1-57-2, Resistant BC_4F_3, and Padituya, the remaining cultivars/genotypes sustained significant yield losses under aphid infestation. Thus, the aphid-resistance gene in SARC1-57-2 is stable against aphids. This resistance genotype can be incorporated into cowpea improvement programmes to breed for aphid-resistant cultivars. Also, the cultivation of such improved cultivars will reduce pesticide usage in cowpea production.

1. Introduction

Cowpea (*Vigna unguiculata* (L.) Walp) is mostly cultivated in tropical Africa, and its edible seeds constitute a major source of protein [1]. Its cultivated area worldwide is approximately 14 million hectares with a global production volume of about 6.5 million metric tons annually. One of the major constraints in the production of cowpea in Africa is severe infestation and damage by various insect pests in the field [2]. This is because of its long history of cultivation on the continent. Thus, it is prone to heavy yield losses or entire crop failure as a result of severe insect pest attacks [3].

Several insect pests attack all growth stages of cowpea, but their economic importance is highly dependent on the environment [4, 5]. Generally, field pests that cause significant losses in cowpea include the stem maggots (*Ophiomyia* spp., Diptera: Agromyzidae), foliage beetles (*Ootheca* spp., Coleoptera: Chrysomelidae), aphids (*A.*

craccivora), flower thrips (*Megalurothrips sjostedti*, Thysanoptera: Thripidae), legume pod borers (*Maruca vitrata*, Lepidoptera: Pyralidae), and the pod-sucking bug (PSB) complex. The major PSBs (Hemiptera: Coreidae) are the spiny brown bugs *Clavigralla tomentosicollis*, *C. schadabi*, *C. hystricodes*, and *Anoplocnemis curvipes*. Others are the cosmopolitan green stink bugs, *Nezara viridula* and *Piezodorus guildinii* (Hemiptera: Pentatomidae); these are of minor economic importance. The pest status of the different insects may vary from one country or region to another, but the losses reported suggest that any one major pest of cowpea can cause significant economic loss if not managed [5, 6].

Among the field pests of cowpea, the aphid is one of the most important pests across Africa as well as in Asia and Latin America [7, 8]. It causes significant yield losses when young seedlings are attacked. Yield losses of 20% to 40% in cowpea due to aphid infestation in Asia and up to 35% in Africa have been estimated [9]. This pest can be controlled by methods such as the use of insecticides, cultural practices, and biological control [5, 10, 11]. However, public concerns about the negative effects of pesticide applications have stimulated a search for more environmentally safe methods such as the use of host-plant resistance in aphid management.

A study by Kusi et al.[12] identified SARC 1-57-2 among other lines as a new source of resistance in cowpea to the cowpea aphids. Their work also confirmed that the main mechanism responsible for aphid resistance in cowpea is antibiosis [8, 13, 14] which is controlled by a single dominant gene [15]. However, insects overcome resistance conferred through single gene inheritance by developing biotypes [16]. For instance, a cowpea line, IT97K-499-35 that was known to be resistant to the aphid in Nigeria [17] was susceptible to the pest in Ghana [12]. This observation was attributed to the existence of a biotype of aphids in Ghana that is more virulent (i.e., able to feed on resistant cultivars) than the biotype in Nigeria where IT97K-499-35 was developed and evaluated.

Although developing and deploying cowpea cultivars that are resistant to aphid attacks are an environmentally friendly way of managing this pest, its effectiveness depends on the stability of the source of the resistance gene. Hence, this study aimed at assessing the stability of aphid-resistance genes identified in some cultivars/genotypes across different cowpea growing ecologies in Ghana and estimating yield loss due to aphid infestation at the seedling stage.

Our data evaluate which resistant cultivar or genotype is stable across all ecologies and will therefore be important for breeding and implementing the host-plant resistance strategy across many geographical areas. Hence, this study was conducted in six regions where cowpea is commonly cultivated in Ghana. These were the Upper East (UER), Upper West (UWR), Northern (NR), Brong Ahafo (BAR), Central (CR), and Volta (VR) regions. Each region was divided into three zones, thus a total of 18 test locations (Figure 1). In terms of ecology, the NR falls within the Guinea Savannah zone, while the UER is in the Sudan Savannah zone. The ecology of the UWR is subdivided into two agroecologies: Guinea Savannah in the southern part and Sudan Savannah in the northern and north-eastern parts. These ecological zones have a unimodal rainfall pattern that commences in May and ends in October, followed by a dry season from November to April each year. Total rainfall ranges between 900 and 1200 mm annually for the Guinea Savannah and that of the Sudan Savannah is less than 1000 mm annually. Mean daily temperatures for these zones range between 26°C and 45°C [18].

The BAR, CR, and VR have a double maximum rainfall pattern annually. For the BAR, the predominant vegetations are the moist semideciduous forest, transitional, and the Guinea Savannah woodland in the southern, middle, and northern parts of the region, respectively. It has mean daily temperatures of 24°C–32°C, and rainfall ranges between 1000 mm in the northern part and 1400 mm in the southern part. The major rains fall between April and July, while the minor season is between September and October, each year. This is followed by a dry spell between November and March.

The ecology of the CR is divided into three—coastal savannah, transitional, and forest zones. It has mean temperatures ranging between 24°C and 34°C, while total annual rainfall ranges between 800 mm and 1500 mm. The major season is from April to July and the minor from September to November. For the VR, its vegetation ranges from coastal to deciduous forests with mean daily temperatures being between 21°C and 34°C. The annual rainfall recorded in this region is between 514 mm and 1100 mm. The major season commences in March and ends in July, while the minor starts in mid-August and ends in October.

2. Materials and Methods

To achieve the objective of this study, two separate experiments were conducted. The first experiment examined the stability of the resistance in five cowpea cultivars/genotypes to aphid infestation. The second assessed the yield losses due to aphid infestation in a range of cultivars/genotypes including a cowpea cultivar that was crossed with a resistant genotype to improve its resistance to the pest.

2.1. Experiment 1: Stability of Aphid Resistance in Different Environments

2.1.1. Multilocational Screening of Cowpea Cultivars/Genotypes for Stability against Aphids. Four test cowpea cultivars/genotypes (i.e., SARC1-57-2, SARC1-91-1, IT97K-499-35, and Zaayura) and a susceptible check (Apagbaala) were used in a multilocation study to assess the stability of their resistance to aphid attacks in different environments. The parentage and/or source of the genotypes/cultivars used for the multilocation test is shown in Table 1. In an earlier study, Kusi et al. [12, 19], identified SARC1-57-2 and SARC1-91-1 to be resistant to the cowpea aphids in the Northern region of Ghana, while Zaayura was found to be tolerant and Apagbaala and IT97K-499-35 as susceptible.

The aphid screening experiments were carried out in mobile screen houses in all six regions. Within each region,

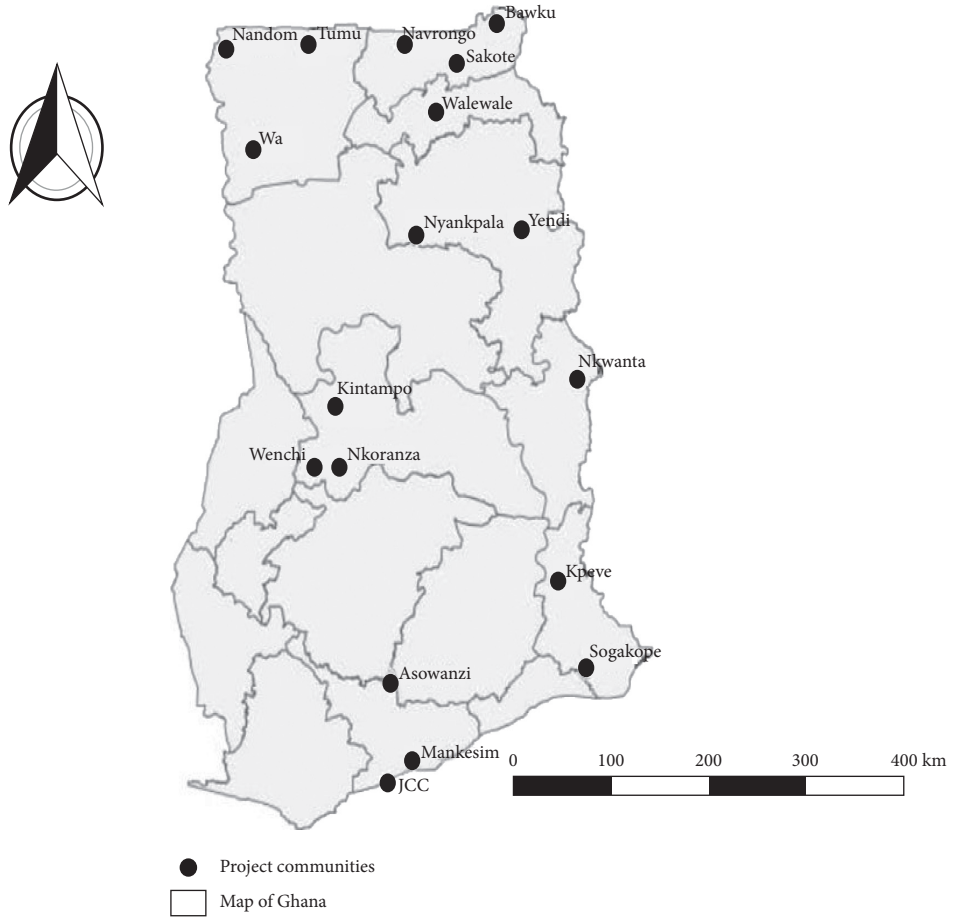

Figure 1: Spatial distribution of the study sites across six regions in Ghana.

Table 1: Description of the cowpea genotypes by the parentage or source.

Cultivar/genotype	Description
Apagbaala	Prima/TVu 4552/California Blackeye No. 5/7977. Cultivar, released in 2002 in Ghana. Largely of exotic background.
SARC1-57-2	Apagbaala/UCR 01-11-52 Breeding line of SARI.
SARC1-91-1	Apagbaala/UCR 01-11-52 Breeding line of SARI.
IT97K-499-35 (Songotra)	Breeding line from the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Cultivar, released in 2004 in Ghana as Songotra.
Zaayura	Marfo-Tuya/UCR 01-15-127-2 released in 2008 in Ghana.
BC_4F_3 (Zaayura//(Zaayura × SARC1-57-2)) Resistant	Marfo-Tuya/UCR 01-15-127-2/SARC1-57-2.
BC_4F_3 (Zaayura//(Zaayura × SARC1-57-2)) Susceptible	Marfo-Tuya/UCR 01-15-127-22/SARC1-57-2.
IT99K-573-1-1	Breeding line from the IITA, Ibadan, Nigeria.
IT99K-573-3-2-1	Breeding line from the IITA, Ibadan, Nigeria.
Padituya	Apagbaala/UCR 01-11-52 released in 2008 in Ghana.

the cowpea cultivars/genotypes were screened at three locations simultaneously. The seedling screening method for cowpea aphid resistance [12, 19] was used to evaluate the cultivars/genotypes. Three seeds of each cultivar/genotype were planted in plastic pots containing sterilized soil. The pots were then arranged in a completely randomized design; there were nine replications of each cultivar/genotype.

To ensure that the specific aphid biotypes present in each location were used, infestation was conducted using aphids collected from farmers' fields in the localities where the trials were undertaken. The collections were first poured on a table with a white background for easy identification and separation of the aphids from predators. The aphids were separated with the aid of a soft painter's brush into containers. This was followed by artificially infesting cowpea seedlings

that were 3-4 days old with 5 aphids in a screen house. Aphids in the range of 4 to 5 days old were used for the infestation, and these were identified from our earlier studies as smaller black adults against larger black adults.

Ten days after the infestation, when damage symptoms became visible, data were collected on the percentage of seedling mortality and seedling vigour until 21 days after infestation when the experiment was terminated. Seedling vigour was rated on a five-point scale [20] where 1 = dead seedling due to aphid damage, 2 = seedling with weak stem and leaves with symptoms of aphid damage, 3 = seedling showing symptoms of aphid damage, 4 = seedling with aphids without symptoms of damage, and 5 = seedling with no aphids.

2.2. Experiment 2: Yield Loss Assessment. To quantify yield losses due to aphid infestation at the seedling stage, the 5 cultivars/genotypes used in Experiment 1 together with 3 farmer preferred cowpea cultivars/genotypes (i.e., IT99K-573-3-2-1, IT99K-573-1-1, and Padituya) and two advanced breeding lines (Resistant BC_4F_3 and Susceptible BC_4F_3) were studied. The advance breeding lines were made up of one that was identified to have inherited the aphid-resistance gene in SARC1-57-2 and another without the gene. The SSR marker CP171/172, linked to the aphid-resistance locus in SARC1-57-2, was used to select the resistant and the susceptible lines from BC_4F_3 population of Zaayura × SARC1-57-2. Table 1 provides detailed information on the cultivars/genotypes used in this study.

For this experiment, control and test fields were established on a research field of CSIR-Savanna Agricultural Research Institute at Manga, Upper East Region. This trial was laid in a randomized complete block design with 6 replications. Each genotype was planted on 2 m × 4 m row plot at a planting distance of 20 cm × 60 cm. The distance between plots was 1 m. Three seeds were sown per stand, and seedlings were thinned to one plant per stand at 3 days after emergence.

The control field was sprayed thrice (i.e., vegetative, flowering, and podding phases) against aphids, thrips, and pod-sucking bugs using Lambda-cyhalothrin (Lambda Super®), a synthetic pyrethroid, at a rate of 20 g active ingredient ha^{-1}. In contrast, the test field was sprayed twice (flowering and podding phases) against thrips and pod-sucking bugs. This was because aphid infestation and damaging effects are mainly limited to the vegetative stage. Hence, genotypes that are resistant to this pest will express this by growing vigorously into the flowering and reproductive stages. The cowpea seedlings were infested with five 4-day-old aphids per seedling [7]. During the period of infestation, the seedlings were confined under an insect proof net in order to limit the damage of the seedlings to only aphids and to prevent effects of predators and parasitoids on the aphids. The aphids used for the on-station infestation were cultured in an insectary where only pure culture of aphids without predators and parasitoids were maintained.

The aphids formed colonies and fed on the seedlings until symptoms of damage were observed on the susceptible seedlings. When the susceptible seedlings became stunted with distorted and yellowing leaves from 16 days after infestation, the aphids were killed by spraying with Lambda Super® at 21 days after infestation. This spraying coincided with the late vegetative stage and the early reproductive phase of the plants. At plant maturity (65 days after planting), the pods were harvested, dried, and threshed, and grain weight was recorded using an electronic balance. Other agronomic data recorded were days to 50% flowering, days to maturity, weight of pods, and weight of biomass at maturity.

Percentage grain yield reduction due to aphid infestation was calculated as

$$\frac{\text{yield in uninfested plot} - \text{yield in infested plot}}{\text{yield in uninfested plot}} \times 100. \quad (1)$$

2.3. Data Analysis. All data were analysed using the GenStat® statistical program (12th edition). The data on the mortality and seedling vigour in the stability experiment were square roots transformed to ensure homogeneity of their variances. Afterwards, a 2-way analysis of variance (ANOVA) with location and genotype as factors was performed to determine the effect of location on the variables measured. When there were no significant location effects, the data were combined and subjected to a one-way ANOVA.

All variables from the yield loss experiments were subjected to a one-way ANOVA. Means of all variables that were significant at the 5% probability threshold were separated using unprotected Fisher's least significance difference (LSD).

To test for the effect of aphid infestation on the number of days to 50% flowering and maturity, the 95% confidence interval (CI) of mean differences between infested and uninfested plants was computed. Again, 95% CI of mean differences was computed between the biomass and grain yields of infested and uninfested plants so as to measure the effects of aphid infestations on the magnitude of losses recorded.

3. Results

3.1. Experiment 1: Stability of Aphid Resistance in Cowpea Genotypes. The results showed that the genotype had significant effect on seedling mortality and vigour ($P < 0.05$). In contrast, there were no significant location and locations × genotypes interaction effects for these variables ($P > 0.05$) (Table 2; see Supplementary material 1).

3.1.1. Seedling Mortality. Across locations, there were significant differences among the cultivars/genotypes in terms of their seedling mortality ($P < 0.05$). The genotype, SARC1-57-2, had the lowest mortality, while IT97K-499-35 had the highest. There were no significant differences between the mortality levels in Apagbaala and IT97K-499-35 (Table 3).

Table 2: Combined analysis of variance for five genotypes across 18 locations.

Source of variation	d.f.	Mean square value	
		Seedling mortality	Vigour
Genotype	4	370605.71**	255.966**
Location	17	9.83 ns	0.1398 ns
Genotype × location	68	15.64 ns	0.1752 ns
Residual	720	13.83	0.1593

Note. ns = not significant at 5% probability level. **Significant at 5% probability level.

Table 3: Effect of aphid infestation on mean seedling mortality and vigour of cowpea cultivars/genotypes.

Cultivar/genotype	Seedling mortality (%)	Seedling vigour score
Apagbaala	96.17 ± 0.311 a	1.17 ± 0.029 d
SARC1-57-2	3.70 ± 0.221 d	3.80 ± 0.031 a
SARC1-91-1	7.99 ± 0.268 c	3.44 ± 0.039 b
IT97K-499-35	96.54 ± 0.304 a	1.17 ± 0.029 d
Zaayura	85.56 ± 0.345 b	1.87 ± 0.026 c
Mean	58.0	2.3
P value	<0.001	<0.001

Note. Data are means ± standard error of means; means in a column followed by different letters are significantly different at 5% probability level.

3.1.2. Seedling Vigour. Again, plant vigour was significantly different among the genotypes ($P < 0.05$). Across locations, SARC1-57-2 had the highest mean vigour score (3.8), while Apagbaala had the lowest (1.7) (Table 3). There was no significant difference between the latter and IT97K-499-35.

3.2. Experiment 2: Yield Loss Assessments

3.2.1. Effect of Aphid Infestation on Flowering and Days to Maturity. There were significant differences between infested and uninfested cultivars/genotypes (d.f. = 59; $t = 15.28$; $P < 0.001$) in terms of the number of days to flowering; flowering was delayed in aphid-infested cowpea across cultivars/genotypes. Similarly, there were significant increments in the number of days to maturity in aphid-infested cowpeas than in those that were not infested (d.f. = 59; $t = 18.89$; $P < 0.001$). For all cultivars/genotypes evaluated, there were significant differences between those infested and uninfested with the pest for their number of days to flowering and maturity ($P < 0.05$) (Table 4).

3.2.2. Effect of Aphid Infestation on Dry Biomass Yield Loss. There were no significant differences between the biomass yields of aphid-infested and uninfested Apagbaala, SARC1-57-2, and Zaayura. In contrast, the difference in the biomass yield between infested and uninfested SARC1-91-1, IT97K-499-35, Resistant and Susceptible progenies of BC_4F_3, IT99K-573-3-2-1, and Padituya was significant.

Among those that showed significant differences in the biomass yield loss, the magnitude of loss was the highest in IT99K-573-3-2-1 and the lowest in the Resistant progeny of BC_4F_3 (Table 5).

3.2.3. Effect of Aphid Infestation on Grain Yield. Except for SARC1-57-2, Resistant progeny of BC_4F_3, and Padituya, there were significant differences between yields of the infested and uninfested plants of the cultivars/genotypes tested. Among those that showed significant differences in yield, the magnitude of the yield loss was highest in the Susceptible progeny of BC_4F_3 and the lowest was in SARC1-91-1. Of those that did not show significant differences between yields of infested and uninfested plants, Padituya had the highest loss, while the Resistant progeny of BC_4F_3 had the lowest (Table 6).

4. Discussion

Multienvironment trials are critical for genotype × environment interaction estimation and for the identification of superior genotypes in the final selection cycles in a breeding program [21]. In most multienvironment trials, a significant genotype × environment interaction reduces the correlation between the phenotype and the genotype, thus retarding the selection progress [22–24]. In this work, genotype × environment interaction effects on the traits studied (aphid damage and plant vigour scores) were not significant. In the absence of the significant genotype by environment interaction effect, few test environments can be used as representatives of a wide range of environments or the performances of genotypes observed in one environment can be replicated in other environments of similar characteristics [22]. Therefore, genotypes that show consistent performance across environments can be considered to have general stability and could be selected to represent a wide range of environments [25, 26]. Consequently, genotypes SARC1-57-2 and SARC 1-91-1 which showed superior performances for aphid damage and plant vigour scores were identified and selected as the most stable for the traits studied.

Within 21 days after aphid infestation, there was slow growth and development of this sucking pest on the resistant genotypes. A study on resistance to aphids in 7 cultivars of *Vicia faba* L. identified tolerance and antibiosis as the mechanisms used to minimize damage in the resistant ones [27]. In this study, the mechanism(s) accounting for the observations were not examined because aphid population growth measurements were not undertaken. Further work is therefore needed in this area. Seedlings of the resistant genotypes grew vigorously, maintained green leaves, and survived despite the aphid infestation due to the retarded growth and development of the pest. In contrast, the aphids reproduced rapidly on the susceptible genotypes and the seedlings showed stunted growth, resulting in severe damage and/or seedling mortality.

Biotypes of an insect species are described by their ability to damage crops with host-plant resistance genes [28–30]. They are intraspecifically classified based on biological rather than morphological characteristics, and they are generally morphologically indistinguishable [31]. Here, the lack of differential response of SARC 1-57-2 and SARC 1-91-1 to aphid infestation at the different locations suggests that unlike Burkina Faso that has more than one aphid biotype [30], Ghana has only a single biotype of this pest. Thus, any possible differences in the *A. craccivora* population in Ghana

Table 4: Effect of seedling stage aphid infestation on number of days to flowering and maturity.

Cultivar/genotype	Days to 50% flowering			Days to maturity		
	Uninfested	Infested	95% CI of mean difference (infested–uninfested)	Uninfested	Infested	95% CI of mean difference (infested–uninfested)
Apagbaala	38 ± 0.21	42 ± 0.49	3.06–4.94**	61 ± 0.48	64 ± 0.26	1.80–3.87**
SARC1-57-2	36 ± 0.21	38 ± 0.31	1.04–2.62**	59 ± 0.45	62 ± 0.21	2.48–4.19**
SARC1-91-1	37 ± 0.21	40 ± 0.42	2.34–3.66**	61 ± 0.37	63 ± 0.21	1.79–2.88**
IT97K-499-35 (Songotra)	38 ± 0.22	39 ± 0.33	0.38–1.96**	61 ± 0.40	63 ± 0.21	1.04–2.62**
Zaayura	42 ± 0.21	48 ± 0.21	4.79–5.88**	65 ± 0.56	70 ± 0.21	3.23–6.10**
Resistant BC_4F_3 (Zaayura// (Zaayura × SARC1-57-2))	41 ± 0.21	46 ± 0.49	2.85–5.15**	65 ± 0.00	69 ± 0.40	3.14–5.20**
Susceptible BC_4F_3 (Zaayura// (Zaayura × SARC1-57-2))	42 ± 0.42	48 ± 0.21	4.90–7.77**	65 ± 0.79	69 ± 0.21	2.03–6.31**
IT99K-573-1-1	38 ± 0.21	40 ± 0.42	2.33–3.66**	60 ± 0.17	63 ± 0.31	1.81–3.52**
IT99K-573-3-2-1	37 ± 0.37	40 ± 0.43	1.40–3.60**	60 ± 0.52	63 ± 0.26	2.34–3.66**
Padituya	42 ± 0.21	47 ± 0.73	2.50–6.83**	65 ± 0.50	68 ± 0.22	1.85–4.15**
Mean	39 ± 0.33	43 ± 0.50	3.11–4.05**	62 ± 0.34	65 ± 0.40	2.86–3.54**

Note. CI = confidence interval; data are means ± standard error of mean. **CI is significant at 5% probability threshold level (i.e., mean differences that do not include zero are significantly different).

Table 5: Effect of aphid infestation on biomass yield of cowpea cultivars/genotypes.

Cultivar/genotype	Biomass yield (kg/ha)			95% CI of mean difference (infested–uninfested)
	Uninfested	Infested	% yield loss	
Apagbaala	3236 ± 74.88	2942 ± 75.45	9.1	−643.1–54.3 ns
SARC1-57-2	3667 ± 88.58	3444 ± 73.79	6.1	−547.9–103.5 ns
SARC1-91-1	3439 ± 130.17	3117 ± 117.38	9.4	−603.5–40.9**
IT97K-499-35 (Songotra)	3719 ± 54.05	3367 ± 47.22	9.5	−894.1–188.5**
Zaayura	4900 ± 94.42	4211 ± 98.95	14.1	−1784–406.6 ns
Resistant BC_4F_3 (Zaayura//(Zaayura × SARC1-57-2))	5028 ± 115.87	4864 ± 29.08	3.3	−317.3–10.4**
Susceptible BC_4F_3 (Zaayura//(Zaayura × SARC1-57-2))	4528 ± 44.67	3972 ± 119.67	12.3	−1094–17.4**
IT99K-573-1-1	3528 ± 86.00	3214 ± 84.95	8.9	−680–52.4 ns
IT99K-573-3-2-1	3278 ± 75.45	2808 ± 84.59	14.3	−792.0–146.9**
Padituya	4947 ± 78.37	4428 ± 74.09	10.5	−992.7–46.17**
Mean	4027	3637		

Note. Data are means ± standard error of means; CI = confidence interval. **CI of mean difference is significant at 5% probability threshold level (i.e., mean differences that do not include zero are significantly different).

Table 6: Effect of aphid infestation on grain yield of cowpea cultivars/genotypes.

Cultivar/genotype	Grain yield (kg)/ha			95% CI of mean difference (infested–uninfested)
	Uninfested	Infested	% yield loss	
Apagbaala	897 ± 250.62	625 ± 152.54	30.3	−423.8–120.7**
SARC1-57-2	850 ± 70.27	808 ± 129.10	4.9	−101.0–17.7 ns
SARC1-91-1	850 ± 237.39	767 ± 149.17	9.8	−141.9–24.8**
IT97K-499-35 (Songotra)	814 ± 231.70	675 ± 132.80	17.1	−227.8–49.93**
Zaayura	775 ± 100.62	569 ± 432.73	26.6	−277.8–133.3**
Resistant BC_4F_3 (Zaayura//(Zaayura × SARC1-57-2))	936 ± 185.71	900 ± 208.24	3.8	−104.7–32.5 ns
Susceptible BC_4F_3 (Zaayura//(Zaayura × SARC1-57-2))	806 ± 66.90	542 ± 199.15	32.8	−396.8–131.0**
IT99K-573-1-1	806 ± 102.42	547 ± 90.44	32.1	−461.3–55.3**
IT99K-573-3-2-1	803 ± 221.68	586 ± 119.15	27.0	−305.2–128.2**
Padituya	1086 ± 440.72	911 ± 284.16	16.1	−400.0–50.0 ns
Mean	862.3	693		

Note. Data are means ± standard error of means; CI = confidence interval. **CI of mean difference is significant at 5% probability threshold level (i.e., mean differences that do not include zero are significantly different).

may be in their genetic composition but not in the biological attribute that could make them overcome the resistant genotypes.

The intensity of damage caused by insect pests varies greatly with the intensity of infestation, duration of occurrence, and stage of growth of the plant, consequently

affecting the crop yield [19, 32]. In this work, aphid infestation delayed flowering and maturity. This observation is corroborated by Kusi et al. [19] who also reported delayed flowering and maturity in medium to late cowpea cultivars; this was attributed to stunted growth as a result of the sucking of plant sap by aphids. In most cases, flowering delayed for at least two days, and this allowed for the production of biomass to compensate for those lost due to aphid feeding.

In terms of biomass and grain yield losses, SARC1-57-2 demonstrated minimal losses between infested and uninfested plants. Also, the Resistant progeny of BC_4F_3 which had its resistance gene from SARC1-57-2, did not incur significant losses under infested condition. The low losses in these resistant genotypes were probably due to their inherent ability to maintain high plant vigour even under aphid infestation. The susceptible genotypes/cultivars, however, showed symptoms of aphid damage such as yellowing of the leaves, stunted growth, and low plant vigour prior to the aphid control [33]. Leaf distortion as a result of aphid infestation reduces the photosynthetic area of the leaves leading to a reduction in the photosynthetic rate of growth and development of the plants; this causes stunted growth and low yield [4, 34].

Most cowpea farmers are resource-poor. Thus, the improvement of Zaayura with the resistance from SARC1-57-2 (i.e., the Resistant progeny of BC_4F_3) resulted in reduction of grain and biomass yield losses from 26.6% to 3.8% and 14.1% to 3.3%, respectively. The resistance of improved Zaayura (i.e., the Resistant progeny of BC_4F_3) to aphids suggests that there will be significant reductions in the application of insecticides at the vegetative stage when this genotype is cultivated. This is because the major constraint in cowpea production at the vegetative stage is aphid attacks [35–37]. Farmers can therefore limit their insecticide applications to only flowering and podding phases to target thrips and pod-sucking bugs. This will limit the harmful effect of exposure to pesticides on farmers and the environment.

5. Conclusion

In conclusion, this study demonstrated that the aphid-resistance gene in SARC1-57-2 is stable against aphids in all the major cowpea growing belts in Ghana. This genotype can therefore be used to improve cowpea cultivars that are susceptible to aphid infestation for cultivation across the major cowpea growing belts in Ghana. Also, the Resistant progeny of BC_4F_3 (Zaayura//(Zaayura × SARC1-57-2)), which had the lowest percentage yield loss in both biomass and grain yield, will therefore be stable against the cowpea aphids across all the major cowpea growing belts in Ghana. The use of this material by farmers will contribute towards reducing the pesticide load in cowpea production in Ghana.

Data Availability

Data are available upon request by writing to the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

Supplementary material 1: mean of seedlings killed (%) and vigour score for the cultivars/genotypes during screening at the different locations in six regions in Ghana. (*Supplementary Materials*)

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