International Journal of Tropical Insect Science (2021) 41:197–208
https://doi.org/10.1007/s42690-020-00193-w

ORIGINAL RESEARCH ARTICLE

Productivity and resistance of okra (*Abelmoschus* spp.) to the cotton aphid *Aphis gossypii* glover (Hemiptera: Aphididae) under tropical conditions

Albert Fomumbod Abang[1,2,3] · Ramasamy Srinivasan[4] · Rachid Hanna[3,5] · Apollin Kuate Fotso[3] · Sevilor Kekeunou[1] · Abdou Tenkouano[6] · Charles-Felix Bilong Bilong[1]

Received: 9 January 2020 / Accepted: 19 June 2020 / Published online: 2 July 2020

Abstract

Aphis gossypii Glover (Hemiptera: Aphididae) is among major arthropods causing significant damage to okra in the tropics. Resistant varieties could reduce aphid infestation and increase productivity. This study was carried out to identify aphid-resistant and high yielding okra accessions for management of the pest. Eleven farmers' varieties and four aphid-resistant accessions from AVRDC were evaluated at its Nkolbisson station in Yaounde, Cameroon. Field screening was done to determine resistance to aphids, days to 50% anthesis and days to 50% commercial maturity. Aphid data was expressed as the area under infestation pressure curve and subjected to statistical analysis based on mean (m) and standard deviation (S.D.). Crop cycle and yield data were subjected to analysis of variance. Accession 'VI033824' was the most resistant to aphids (474 ± 41.9 per leaf) with yield 0.76 ± 0.26 t/ ha whereas the yield of the highly susceptible Babungo (1519.8 ± 0.0 aphids) was 1.33 ± 0.07 t/ha, 75.5% higher that the yield of the only resistant variety. *Abelmoschus esculatus* was less attacked (601.4 ± 60.0 aphids) by aphids than *Abelmoschus caillei* (826.0 ± 71.6 aphids; df = 1, 41; Pr {>Chi} = 0.037). The yield of *A. caillei* species were higher (1.26 ± 0.14 t/ha) than *A. esculentus* species (0.43 ± 0.08 t/ha; df = 1, 41; Pr {>Chi} = 0.0002). Hence, varieties with resistance, tolerance to aphids and earliness could be incorporated into integrated pest management of aphids and enhance productivity of okra.

Keywords Farmers' varieties · Resistant to *Aphis gossypii* · Days to anthesis · Commercial maturity · Okra yield

Introduction

Okra (*Abelmoschus* spp.) is a vegetable crop grown and consumed fresh or dry depending on the location. It is one of the most important indigenous vegetable cultivated in Sub-saharan Africa. Like most vegetables, okra provides majority of mineral required of healthy diets in the tropics and in Africa. Some of these minerals include Potassium, Sodium, Magnesium, Calcium, Iron, Zinc, Manganese and Nickel (Moyin-Jesu 2007). It also has high fiber content and 30% of the recommended levels of vitamin C, folate and vitamin A (NAP 2006). However, beta carotene (vitamin A) or retinol is absent in dried okra (Avallone et al. 2008). The presence of high content of carbohydrates, proteins and glycol-protein has also been reported (Asawalam et al. 2007; Manach et al. 2005). Fresh okra pods are the most important vegetable source of viscous fiber, an important dietary component for the reduction of cholesterol (Kendall and Jenkins 2004) and the viscosity eases consumption of hard foods (Schippers 2000). Increasing okra production can diversify vegetable production systems in sub-Saharan Africa and help improve diets, incomes and livelihood (Hughes 2009). Worldwide production of okra is estimated at 7.83 million t annually (FAO 2015). *Abelmoschus caillei,* commonly called West African okra accounts for only 5% of the total world production of okra (Siemonsma and Kouamé 2004), but it is a very important crop in tropical areas. Among the vegetables cultivated in Cameroon, farmers rank

✉ Albert Fomumbod Abang
a.abang@cgiar.org

1 Faculty of Science, University of Yaoundé I, Yaoundé, Cameroon
2 AVRDC – The World Vegetable Center, Yaoundé, Cameroon
3 International Institute of Tropical Agriculture (IITA), Yaoundé, Cameroon
4 AVRDC – The World Vegetable Center, Tainan, Taiwan
5 Present address: Institute of the Environment and Sustainability, Congo Basin Institute, University of California, Los Angeles (UCLA), Box 11 951496, Los Angeles, CA 90095, USA
6 West and Central African Council for agricultural research and development, Dakar, Senegal

okra as fourth and among the top five in Africa (Ellis-Jones et al. 2008). In Cameroon, the two okra species cultivated, *A. caillei* and *A. esculentus* (common okra) combined represent the second most important vegetable in the market after tomato (Schippers 2000). *A. caillei* is now the most cultivated species in Cameroon and seems to be a suitable species for tropical-humid regions with better adaptation and tolerance to some biotic stresses. Nevertheless, *A. esculentus* is preferred because of its shorter production cycle. West African okra with a longer productive period compared with common okra provides an attractive feature for home gardening while common okra that flower early, and with a shorter productive period is suitable for market gardening (Siemonsma and Kouamé 2004). Although 95% of okra production in the world is from common okra, it is only in West and Central Africa (WCA) that both species are cultivated and sharing the market equally. WCA accounts only for about 10% of the world's production of okra (Siemonsma and Kouamé 2004; Siemonsma and Kouamé 2004).

The cotton aphid, *Aphis gossypii* Glover, is one of the major biotic constraints to Okra production. In Cameroon aphids have also been identified as economically important pests of okra (Kekeunou et al. 2006; Djiéto-Lordon et al. 2007; Abang et al. 2014). Heavily infested plants show distorted and stunted leaves and reduced yield Pests including aphids are becoming resistant to pesticides and *A. gossypii* has developed resistance to carbamates, organophosphates, pyrethroids, and neonicotinoids (Tabacian et al. 2011). (Wanja et al. 2001). Yield losses can be up to 57% (Shannag et al. 2007) when aphid infestation is exceedingly higher (>1000 aphids per plant) Nderitu et al. 2008). The high infestation and severity of damage by this pest has led to rampant use of chemical pesticides for its control. About 90% of vegetable farmers in Cameroon used chemical pesticides (Abang et al. 2013). Chemical pesticides increase cost of production, eliminate beneficial organisms and contribute to environmental degradation and pest resistance (Ajayi 2005). Resistant plant varieties form an important component in integrated pest management strategies, to reduce chemical spray, environmental damage and cost of production. Plant resistance to insects is the genetically inherited qualities that result in a plant of one variety or species being less damaged than a susceptible plant lacking these qualities (Kogan and Paxton 1983) with several types described as follows: Pseudo or false resistance in susceptible plants is resistance due to early planting, low levels of insect infestation, temperature differences, day length, soil chemistry and plant or soil water content; Associational resistance refers to a normally susceptible plant growing in association with a resistant plant, and deriving protection from insect predation; Induced resistance, which is the enhancement of a plant's pest defense system in response to external physical or chemical stimuli (Kogan and Paxton 1983), occurs in many crops due to the elicitation of endogenous plant metabolites (Pearce et al. 1991).

Plants resistance to herbivores had long been categorized into three mechanisms: antixenosis, antibiosis, and tolerance (Painter 1951). The term "mechanisms" of resistance was replaced by Kogan and Ortman (1978) with the term "categories" of resistance. Horber (1980) called the three as functional categories while Smith (1989) termed them functional modalities of resistance. The resistance due to negative effects of a plant on the biology of an insect attempting to use it as a host is called antibiosis (Smith 1989). Painter (1951) stated that antibiosis refers to the adverse effects on insect life history when a resistant plant variety is used as a food source. Non-preference or Antixenosis (Kogan and Ortman 1978) means simply that a given plant is not a preferred host of an insect for feeding and oviposition. Smith (1989) stated that antixenosis describes the inability of a plant to serve as a host to particular herbivore insect. The third category of resistance is tolerance; this is the ability of the plant to withstand insect damage and continue to grow and produce. The expression of tolerance is determined by the inherent genetic ability of a plant to outgrow an insect infestation or to recover and add new growth after the destruction or removal of damaged tissues (Smith 1989). Factors affecting tolerance include plant vigour and regrowth of damaged tissues (Metcalf and Luckman 1994). The mechanisms involved are six physiological (increased net photosynthetic rate after herbivory, high relative growth rates, increased branching or tillering, pre-existing high levels of carbon storage in roots, increased resource allocation from root to shoot after damage (Strauss and Agrawal 1999) and up-regulation of detoxification mechanisms as a response to counteract harmful effects of herbivory (Koch et al. 2016). Possible morphological mechanisms include protected meristems, number of meristems, and developmental plasticity (Rosenthal and Kotanen 1994). The evolution of aphid has been described as strongly shaped by dependence on their host plants. Both chemical and morphological plant defenses mediate resistance to insect pests through mechanisms of resistance such as olfactory repellents, feeding or oviposition deterrents, and toxins, or the absence of feeding or oviposition stimulants. Allelochemicals and volatiles produce an unfavourable taste or smell to repel herbivores, and to attract beneficial organisms such as predators, parasitoids and pollinators (Kessler and Baldwin 2001). Morphological defences are structural features of the plant, such as pubescence, that are unfavourable for insects (Zarpas et al. 2006). Hosts with some unfavourable characteristics such as tall, open canopy, smooth leaves (Nibouche et al. 2008), red coloured varieties (Matthews and Tunstall 1994) are always less severely attacked by arthropod pests, especially *Aphis gossypii* Glover (Hemiptera: Aphididae). Morphological or structural characteristics such as silica content, leaf toughness and size, deceptive plant structures, also play a vital role in enhancing plant resistance (Deguine and Hau 2001).

Some reports have confirmed the availability of aphid-resistant okra genotypes (Sumathi 2005; Anitha and Nandihalli 2009). However, only few varieties were studied in these reports. For instance, only 15 local cultivars were screened in Tamil Nadu, India by Sumathi (2005) and two ccultivars were found to be moderately resistant. Unlike most vegetables that require a nursery, okra can be sown directly into the field without transplant. This unique advantage over other vegetables makes it easier to grow okra. However, apart from pest and diseases, the growth of okra may face challenges such as growth production cycle, species adaptation, seed dormancy due to either thick seed coats or improper seed storage method (Siemonsma and Kouamé 2004; Siemonsma and Kouamé 2004). One of the most important selection factors for consumer is mucilage content responsible for sliminess. In Cameroon and most West African countries *A. caillei* is preferred by consumers because it is slimier (Avallone et al. 2008). The use of host plant resistance is a core component of integrated pest management. This is because of the fact that chemical pesticides will be reduced on tolerant and moderately resistant varieties. This method also allows the proliferation of potential natural enemies, and other habitat management options such as intercropping, and crop rotation could be incorporated, thereby reducing the cost of production. The world health organization estimates that over 200,000 people die globally through synthetic pesticide exposure annually (Belmain et al. 2013) due to synthetic pesticide overuse. Aside from the environmental problem associated with the use of synthetic pesticides (insecticides) is the issue of resistance and pest resurgence (Ojo 2016). Pest resistance implies that a pest is resistant to a specific pesticide rendering it ineffective in the control of the pest while pest resurgence emanates from scenario whereby pests become more virulent and difficult to control. Hence, the need to turn to the use of plant resistance which have been shown by researchers over the years to effectively control pests without causing the environment high cost in terms of preservation of the biodiversity and huge financial outlay (Wratten et al. 2007). The objectives of this work were to identify aphid resistant and high yielding okra accessions with shorter growth cycle for cultivation in humid and tropical climates. The goal is to enhance productivity, management of aphid pest of okra and to improve incomes and livelihoods of vegetable farmers in sub-Saharan Africa.

Material and methods

Study site

The experiments were conducted at AVRDC's station located in Nkolbisson, Yaounde-Cameroon at Latitude 03°51.791'N; Longitude 011°27.706′E and Elevation, 747 m. The site is in the warm and humid forest agro-ecological zone with bimodal rainfall. The trial was conducted between October 2012 and March 2013, with only two wet months; October 2012 and March with wetness experienced at week one of October and during week one and four of March (Fig. 1).

Sources of germplasm

Four aphid-resistant accessions from AVRDC and 11 farmers' varieties collected from major okra producing locations in Cameroon were screened from October 2012 to March 2013 (Table 1). The varieties were never previously studied for any of the plant features which confer insect resistance. The farmers' varieties were collected randomly from farmers during a baseline survey. AVRDC accessions were obtained from AVRDC's Genetic Resources and Seed Unit, Taiwan (Table 1). The four AVRDC varieties were previously identified as resistant or moderately resistance to aphids during preliminary screening in 2012 (Abang 2018), where, 96 accessions were screened from March to July (in Taiwan), and 66 were rated as moderately resistant but only four were testes here because of lack of seeds.

Method

The seeds were sown three per stand with plant spacing of 1 m, and a row to row spacing of 1 m and thinned to one plant per stand at 2 weeks after sowing. The trial was maintained following customary cultural practices without any pesticide application. A drip irrigation system was installed in the field to ensure regular supply of water since the trial was conducted during the dry season. The experiment was laid out in Randomized Complete Block Design with three replications. Each replicate was a plot of 20 m long and 3 m wide. Three rows of okra were sown per plot with 20 plnts per row. The young fruits were picked when still immature (3–6 cm long), before the differentiation of fibres and before the seeds are fully developed, every 3 days and counted for productivity. The date of flowering was recorded at 50% anthesis and fruiting stage was determined by recording the date at 50% commercial maturity. Epicalyx segments were observed and species with large epicalyx were considered *A. manihot* (var. caillei) (Siemonsma 1982). The field was exposed to natural infestation of aphids and the aphid population was counted at weekly intervals starting 4 weeks after transplanting and continued till end of production of each variety. Ten plants of each accession were randomly selected from the middle row, and three leaves—one from the bottom, middle and top strata—were also selected randomly, and the aphids on each plant and leaf were counted directly and the abundance of aphids recorded.

Data were expressed as area under infestation pressure curve (AUIPC), calculated using the formula of Shaner and Finney (1977) as follows:

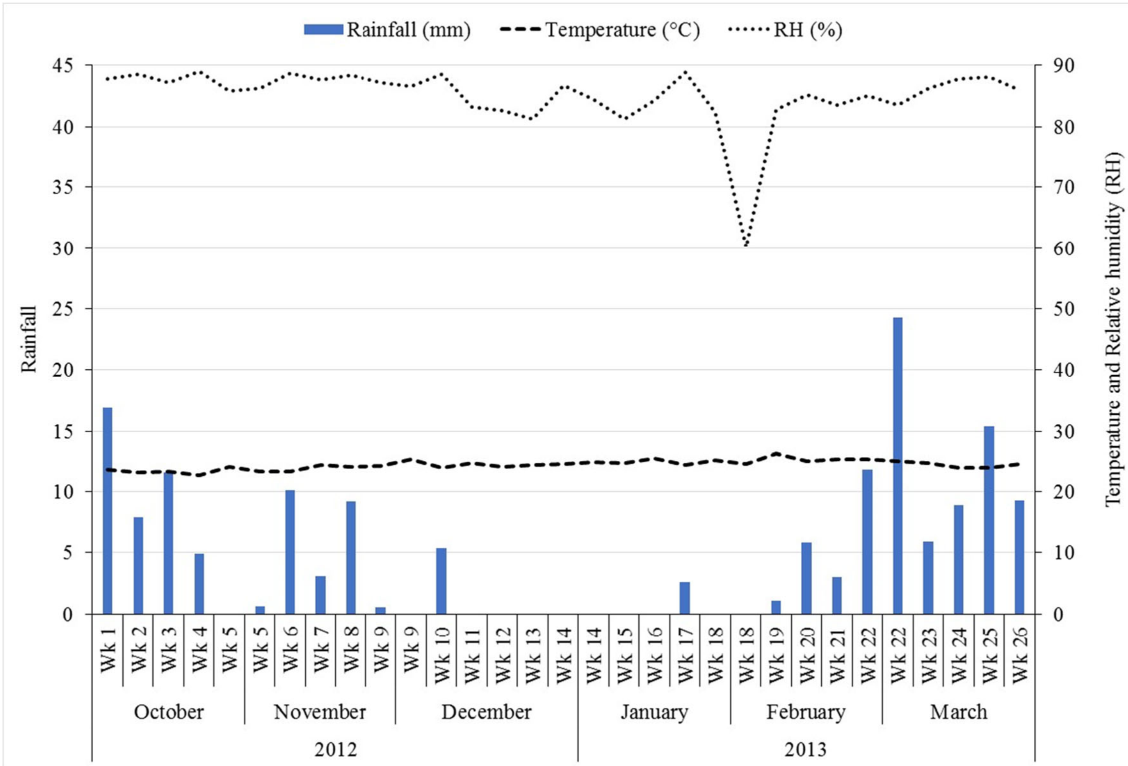

Fig. 1 Pattern of climatic factors for the bimodal warm, humid forest of Yaoundé during the period of the study

$$\sum_{i=1}^{n=1} \frac{(Y_i + Y_{i+1})}{2} (t_{i+1} - t_i)$$

Y number of insects at time t
n number of assessment times
t assessment da

The AUIPC values (N) were subjected to a statistical analysis based on mean (m) and standard deviation (sd) (AVRDC 1979) and categorized as resistant or susceptible as described in Table 2.

Data on days to anthesis, days to commercial maturity, duration of growth cycle, aphids per leaf and yield were analyzed using R version 3.6.2. Generalized Linear Model (GLM) with a Poisson error (log link) was used to determine

Table 1 Okra germplasm evaluated and source or location where it was collected

Accession	Source of germplasm and agro-ecological zones
Babungo Baba I	From farmer's field in the western highland in the North-West region with monomodal rainfall
Njombe green Njombe red	From farmer's field in monomodal warm and humid forest in the Littoral region
Njombe Caffeier	
Maroua	From farmer's field in the sudano-sahelian zone in the Far-North region with monomodal rainfall
Ebebda green Evodoula 6 months	From farmer's filed in the bimodal warm and humid forest in the Center region
Munya Buea Small Soppo	From farmer's field in the monomodal warm and humid forest of South-West region
Bityili giant	From farmer's field in the bimodal warm and humid forest in the South region
VI046537	AVRDC
VI033778	AVRDC
VI033796	AVRDC
VI033824	AVRDC

Table 2 categories of resistance status used to classify the varieties as resistant or susceptible base on mean and standard deviation

Range of AUIPC (N) value	Category
$N < (m–2sd)$	Highly Resistant
(m–2sd) < N < (m–sd)	Resistant
(m–sd) < N < m	Moderately Resistant
m < N < (m + sd)	Moderately Susceptible
(m + sd) < N < (m + 2sd)	Susceptible
N > (m + 2sd)	Highly Susceptible

how the numbers of aphids per leaf were affected by varieties. In case of over-dispersion of data, a GLM with quasi -Poisson distribution of errors was applied. For Yield data, days to anthesis, days to commercial maturity and duration of growth cycle, after determining the yield in tonnes per ha, analysis of variance (ANOVA) in a GLM with Gaussian error was used to examine the effects of varieties. Chi-square test and one-way analysis of variance (ANOVA) were conducted to assess any differences between species, for all parameters measured. Tukey's test was employed to classify mean values of different treatments when F-values were significant ($p < 0.05$).

Results

Crop cycle

The results showed significant differences among varieties in days to 50% anthesis (F = 8.58; df = 14, 30; $P < 0.0001$), in days to 50% commercial maturity (F = 12.92; df = 14, 30; P < 0.0001) and in duration of crop cycle (F = 17.07; df = 14, 30; P < 0.0001). The variety with the longest days to 50% anthesis (100 ± 5.8 days) was Bityili giant and had the longest days to 50% commercial maturity (110 ± 5.3 days) and among the longest crop cycle (135 ± 0.0 days). This was followed by the highly susceptible variety Babungo with 80 ± 3.6 days to anthesis, 95 ± 4.0 days to commercial maturity and 135 ± 0.0 days to end of cycle. The resistant variety was the second with shorter days to anthesis (52 ± 0.5), days to commercial maturity (61 ± 1.5) and end of cycle (94 ± 0.6; Fig. 2). Most farmers' varieties were late flowering (60–100 days to anthesis) but three of the AVRDC accessions (VI033796, VI033824, and VI033778) including the farmer's variety from Maroua were early flowering (52–54 days to anthesis) (Fig. 2). All farmers' varieties except the Maroua variety were *Abelmoschus caillei* with large epicalyx, and all four AVRDC accessions were *A. esculentus* with spiny epicalyx. Days to 50% commercial maturity followed a similar trend as days to 50% anthesis. The days to 50% commercial maturity for farmers' varieties range from 67 to 110 days, and from 60 to 80 days for the AVRDC accessions and the Maroua variety (Fig. 2).

Yield evaluation

The present results also showed significant difference in productivity among the varieties F = 5.59; df = 14, 30; $P < 0.0001$). The yield in farmers' varieties and *A. caillei* species were higher (0.7–2.2 t/ha) than AVRDC accessions and *A. esculentus* species (0.1–0.8 t/ha; Fig. 3). The highly susceptible accession (Babungo) was among the varieties with the highest yield (1.3 ± 0.1 t/ha) such as Njombe red (2.2 ± 0.6 t/ha); moderately susceptible, Evodoula 6 months (2.0 ± 0.4 t/ha) and Small Soppo (1.8 ± 0.6 t/ha); all being moderately resistant (Fig. 3). The yield of the only susceptible variety (highly susceptible) Babungo (1.33 ± 0.07) was 75.5% higher that the yield of the only resistant variety VI033824 (0.76 ± 0.26 t/ ha).

Screening for resistance to aphids

None of the farmers' landraces was resistant to aphids. One variety was highly susceptible, 4 moderately susceptible and 9 moderately resistant. Only one accession (VI033824) was resistant to aphid ($N = 474.3 \pm 41.9$), mean (m) 781.96 and standard deviation (SD) 287.0, following the Area Under Infestation Pressure Curve (AUIPC)(N) (Table 3). Significant differences were recorded among the varieties in number of aphids per leaf (F = 17.55; df = 15,25; $P =$ 0.0001).

Highly susceptible (HS), Moderately susceptible (MS), Moderately resistant (MR) Resistant (R). Mean values with different letter(s) are significantly different *(Tukey test $\alpha =$ 0.05)*.

Effect of okra species

Abelmoschus caillei flower late with average of 70.96 ± 2.55 days (60–100 days), whereas *A. esculentus* flower early with average 55.40 ± 1.74 days (52–54 days) and there was significant difference between the two (df = 1, 41; Pr(>Chi) = 0.0003; Table 4; Fig. 2). A similar trend was observed between the two species in terms of days to commercial maturity (df = 1, 41; Pr (>Chi) = 0.0003) and end of production (df = 1, 41; Pr (>Chi) < 0.0001). The duration of days to commercial maturity in *A. esculentus* was 64.80 ± 2.15 days (60 to 80 days), while *A. caillei* took 81.68 ± 2.72 days (70 to 110 days) before harvesting is started on 50% of the plants (Table 4; Fig. 2). Three varieties of *A. esculentus* (VI033796, VI033824, and VI033778) stop production at 3 month and two (VI046537 and Maroua) were able to reach 4 months. All the *A. caillei* varieties extended their production period to about four and a half-month (133.71 ± 0.72 days) while that

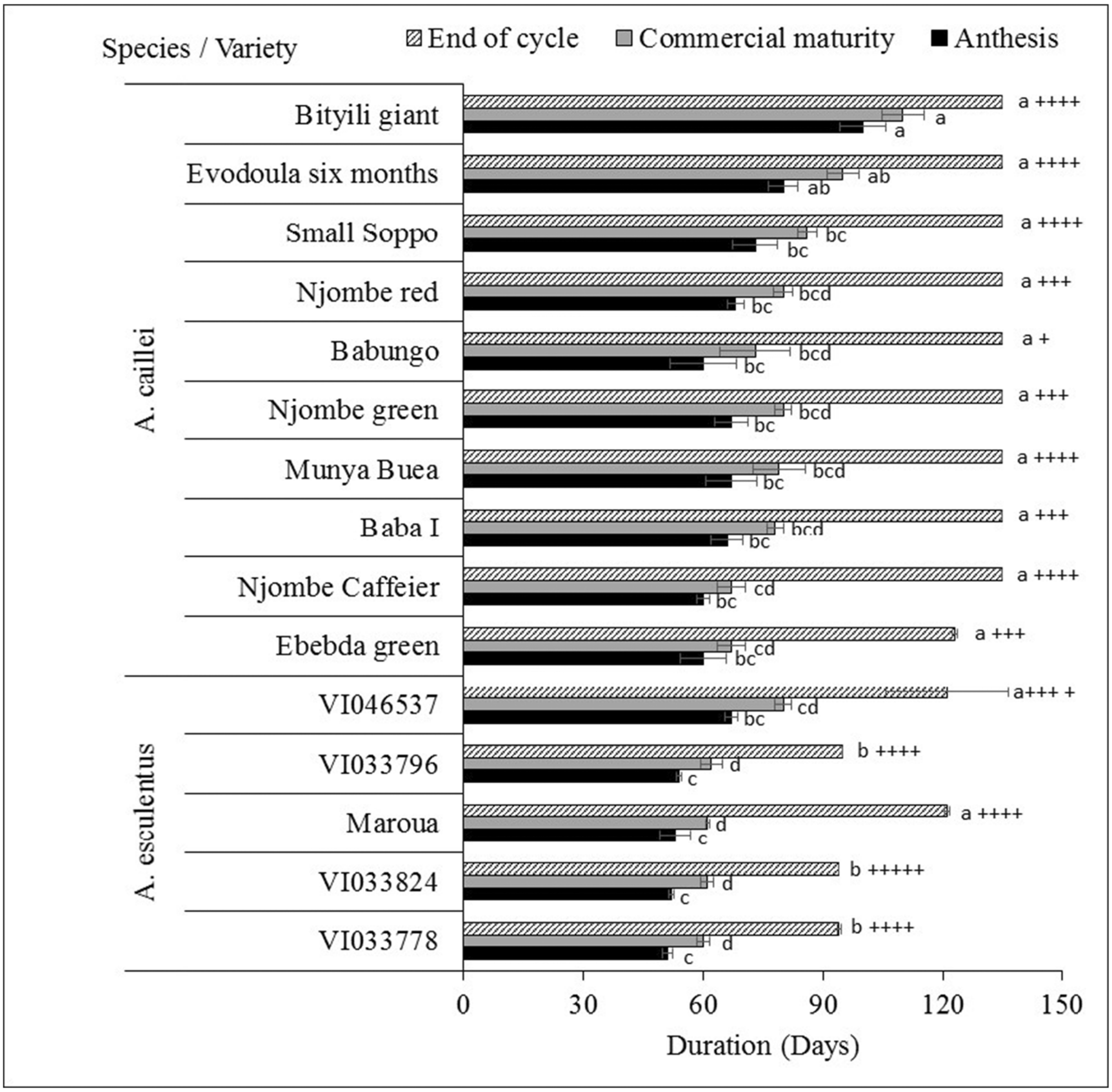

Fig. 2 Phenological durations of the 15 okra accessions in days to flowering, commercial maturity and end of production evaluated in Yaoundé from October 2012 to March 2013, +++++resistant, ++++moderately resistant, +++moderately susceptible, ++susceptible, +highly susceptible. For the same bars pattern, mean values represented by bars with different letter (s) are significantly different *(Tukey test α = 0.05)*

of *A. esculentus* ended at 105.00 ± 4.35 days (Table 4). *A. esculatus* was less attacked (601.4 ± 60.0 aphids) by aphids than *A caillei* (826.0 ± 71.6 aphids). There was a significant difference between the two species in infestation (df = 1, 41; Pr (>Chi) = 0.037; Table 4). The yield of *A. caillei* species were significantly higher with average 1.26 ± 0.14 t/ha than *A. esculentus* species with average 0.43 ± 0.08 t/ha (df = 1, 41; Pr (>Chi) = 0.0002; Table 4).

Effect of strata on infestation by aphids

Generally, aphid populations were highest on the middle leaves for nine out of the 15 varieties, highest on bottom leaves of five out of the 15 varieties and highest on top leaves on none. On the bottom stratum infestation ranged from 545.5 ± 45.2 on Maroua variety to 1223.6 ± 186.9 on variety Njombe green. On the middle stratum infestation ranged from 507.7 ± 36.0 on the resistant variety VI033824 to 2731.2 ± 0.0 on the highly susceptible variety Babungo. Lastly on the top stratum infestation ranged from 293.2 ± 83.4 on Bityili giant to 932.8 ± 0.0 on highly susceptible Babungo (Fig. 4). Significant difference among varieties were observed on with the middle stratum (F = 5.26; df = 14, 27; *P* = 0.0001; Fig. 4). On the middle stratum, the highest infestation (2731.2 ± 0.0) was recorded on highly susceptible variety (Babungo) and the lowest on Njombe cafeier with 478.8 ± 78.5 aphids, while the resistant variety (VI033824) recorded 507.7 ± 36.0 aphids per leaf (Fig. 4).

For each variety, significant difference among strata were observed only on four varieties. These were Baba I (F = 10.64;

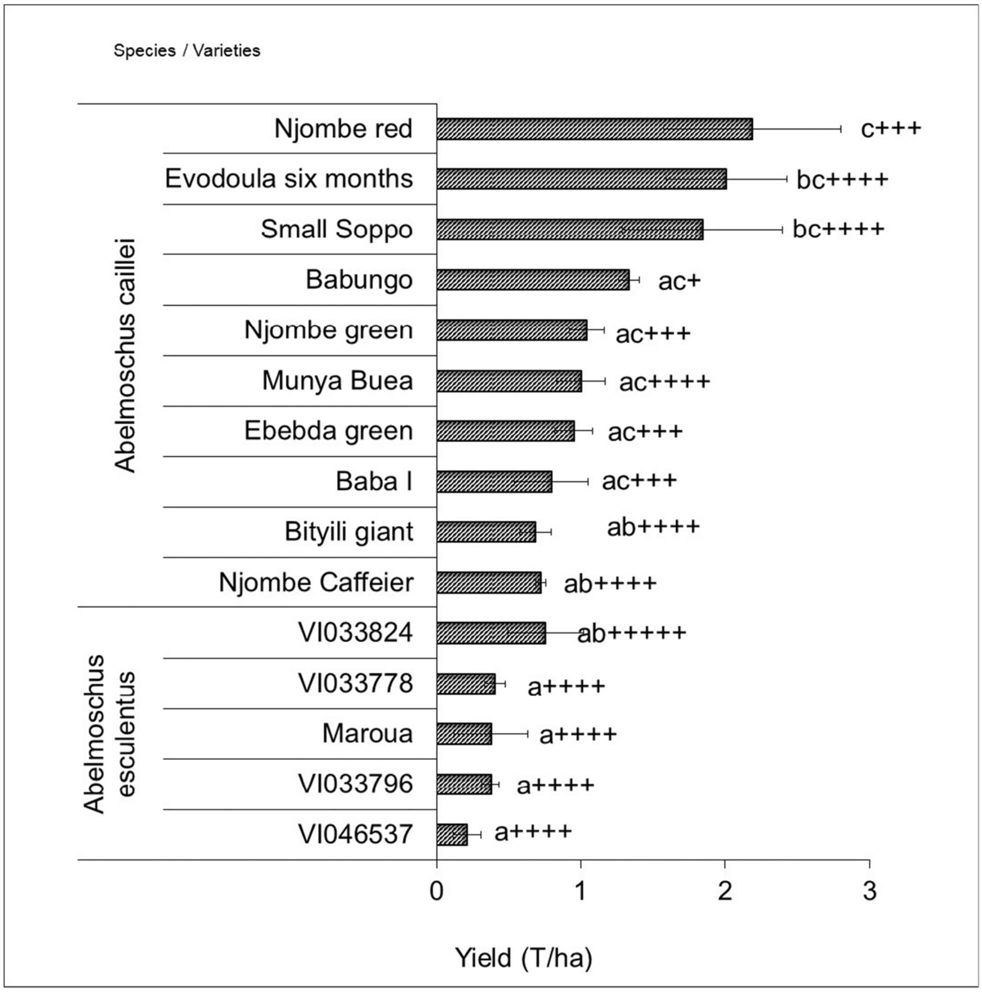

Fig. 3 Okra yield of 11 farmers' and 4 aphid-resistant accessions during second advanced replicated screening from October 2012 to March 2013 in Yaoundé, +highly susceptible, ++susceptible, +++moderately susceptible, ++++moderately resistant, +++++resistant. Mean values represented by bars with different letter(s) are significantly different *(Tukey test* $\alpha = 0.05$*)*

df = 2; $P = 0.011$) with 621.2 ± 25.7, 1081.3 ± 28.6, 759.8 ± 119.3 aphids; Babungo (582.94; df = 2; $P < 0.0001$) with 932.8 ± 0.0, 2731.2 ± 0.0, 1094.3 ± 0.0 aphids; Njombe green (F = 5.99; df = 2; 0.04) with 817.3 ± 17.5, 1677.9 ± 240.1, 1223.6 ± 186.9 aphids; Small Soppo (F = 16.11; df = 2; $P =$ 0.004) with 309.1 ± 25.5, 741.0 ± 63.2, 1054.2 ± 146.4 aphids on top, middle and bottom stratum respectively (Fig. 4) .

Discussion

None of the varieties obtained from farmers was resistant to *A. gossypii*. This indicates that in Cameroon, this insect is a serious pest of okra, and that the varieties cultivated by farmers are highly prone to aphid infestation. Okra has been among the top crops sprayed to control insect pest with aphids occupying the top position (Abang et al. 2013, 2014). The non-significant effect of aphids on susceptible varieties in yield during the current study have shown that intervention by controlling with pesticides would not justified. These crops produced higher yield than the other resistant accessions. This indicates that the type of resistance to aphid found in these okra accessions is tolerance. Resistance through tolerance may be achieved through higher plant vigour. Vigorous plants harbour more pests and provide more food for insect development, growth and reproduction. Plant vigour compensates for insect feeding damage and consequently ensures good crop yields, thereby augmenting the crop's tolerance to pests (Ndemah 1999; Ndemah et al. 2003; Chabi-Olaye et al. 2005). These two most susceptible varieties were the most productive hence; tolerance is an obvious category of resistance found in these farmers varieties. Accessions with lower yield belonged to *A. esculentus* and were the least infested by aphids. The high yielding varieties were *A. caillei* and classified as highly susceptible, moderately susceptible or moderately resistant to aphids due to heavy infestation. This corroborates the results of Siemonsma (1982) that *A. caillei* is better adaptation under humid zone and tolerant to pests and diseases. Despite heavy infestation, the yields were still significantly higher than those of *A. esculentus*. This shows that *A. caillei* is more tolerant due to its vigorous nature; it can harbour higher aphid population than *A. esculentus* but is so well developed vegetatively such that they easily compensate for aphid feeding injury as described by Strauss and Agrawal

Table 3 Number of aphids per leaf counted in the field during the experiment and presented as area under infestation pressure curve, showing resistance status

Accession	AUIPC	Resistance status	Species	Origin
Babungo	1519.8 ± 0.0 A	HS	*A. caillei*	Cameroon
Njombe green	1219.2 ± 121.3 AB	MS	*A. caillei*	Cameroon
Ebebda green	1015.6 ± 336.6 ABC	MS	*A. caillei*	Cameroon
Njombe red	929.1 ± 196.1 ABC	MS	*A. caillei*	Cameroon
Baba I	785.5 ± 40.8 BC	MS	*A. caillei*	Cameroon
VI046537	763.4 ± 35.3 BC	MR	*A.esculentus*	Thailand
Munya Buea	755.9329.4 BC	MR	*A. caillei*	Cameroon
Evodoula 6 months	705.4 ± 139.1 BC	MR	*A. caillei*	Cameroon
Small Soppo	696.5 ± 68.5 BC	MR	*A. caillei*	Cameroon
VI033778	671.0 ± 114.0 BC	MR	*A esculentus*	Malaysia
Maroua	582.2 ± 111.0 BC	MR	*A.esculentus*	Cameroon
Njombe Caffeier	551.1 ± 203.2 C	MR	*A. caillei*	Cameroon
Bityili giant	544.4 ± 163.3 C	MR	*A. caillei*	Cameroon
VI033796	516.0 ± 265.0 C	MR	*A esculentus*	Malaysia
VI033824	474.3 ± 41.9 C	R	*A.esculentus*	Philippines
Mean (m)	781.96			
Standard deviation (sd)	287.02			
$F_{(15,25df)}$-value	17.55			
P value	0.0001			

(1999). They described the physiological mechanisms involved such as increased net photosynthetic rate after herbivory, high relative growth rates, increased branching or tillering, pre-existing high levels of carbon storage in roots, increased resource allocation from root to shoot after damage, and morphological mechanisms include protected meristems, number of meristems, and developmental plasticity (Rosenthal and Kotanen 1994).

Abelmoschus caillei is the most common species of okra cultivated in Cameroon. Okra seeds were collected from 11 farmers' fields; two from the western highland, five from the monomodal warm and humid forest, 3 from the bimodal warm and humid forest, and 1 from the Sudano-sahelian zone. The only *Abelmoschus esculentus* species among the farmers' varieties studied was the single collection from the sudano-sahelian zone, and the seeds were obtained from local sellers in one of the local markets in Maroua, Cameroon. This observation support findings that were long reported by Siemonsma (1982) that *A. caillei* (the Guinean okra) had replaced common okra (*A. esculentus*) in the tropical-humid regions because of its better adaptation under humid zone and tolerance to biotic stresses. Kumar et al. (2010) also mentioned that under very limited rainfall in the Sudano-Sahel zones, *A. esculentus* was preferred compared to *A. caillei* because of earliness. Although Siemonsma and Kouamé (2004) reported that *A. caillei* accounts for only 5% of the total world production of okra, it is a very important crop in tropical areas of Cote d'Ivoire, Benin, Cameroon, Nigeria, Ghana and Togo (Kumar et al. 2010). This explains why the only *A. esculentus* species was collected from the Sudano-sahelian zone of Cameroon, and its importance in the semi-arid area. The fact that only one variety was resistant out if 15 may indicate that the sources or okra resistance to aphids are limited as reported by (Dogimont et al. 2010). However, some reports have confirmed the fact that it is possible to obtain okra genotypes resistant to aphids (Sumathi 2005; Anitha and Nandihalli 2009). Nevertheless, these studies were based on reports on a limited number of local genotypes screened. For instance, in Tamil Nadu, India, Sumathi (2005) worked on only 15 local varieties and two were found to be moderately resistant. In the present study, 15 accessions/varieties were also screened though only 11 varieties were local; the 4 AVRDC accessions can still be considered local because they are not breeding lines. Several pest species were

Table 4 Effect of okra species on crop phenological durations, infestation and yield

Species	Days to anthesis (days)	Days to commercial maturity (days)	End of production (days)	Infestation (aphids/leaf)	Yield (t/ha)
A. Caillei	70.96 ± 2.55	81.68 ± 2.72	133.71 ± 0.72	826..0 ± 71.6	1.26 ± 0.14
A. esculentus	55.40 ± 1.74	64.80 ± 2.15	105.00 ± 4.35	601.4 ± 60.0	0.43 ± 0.08
df	1, 41	1, 41	1, 41	1, 41	1, 41
Pr (>Chi)	0.00003	0.00003	< 0.0001	0.037	0.00003

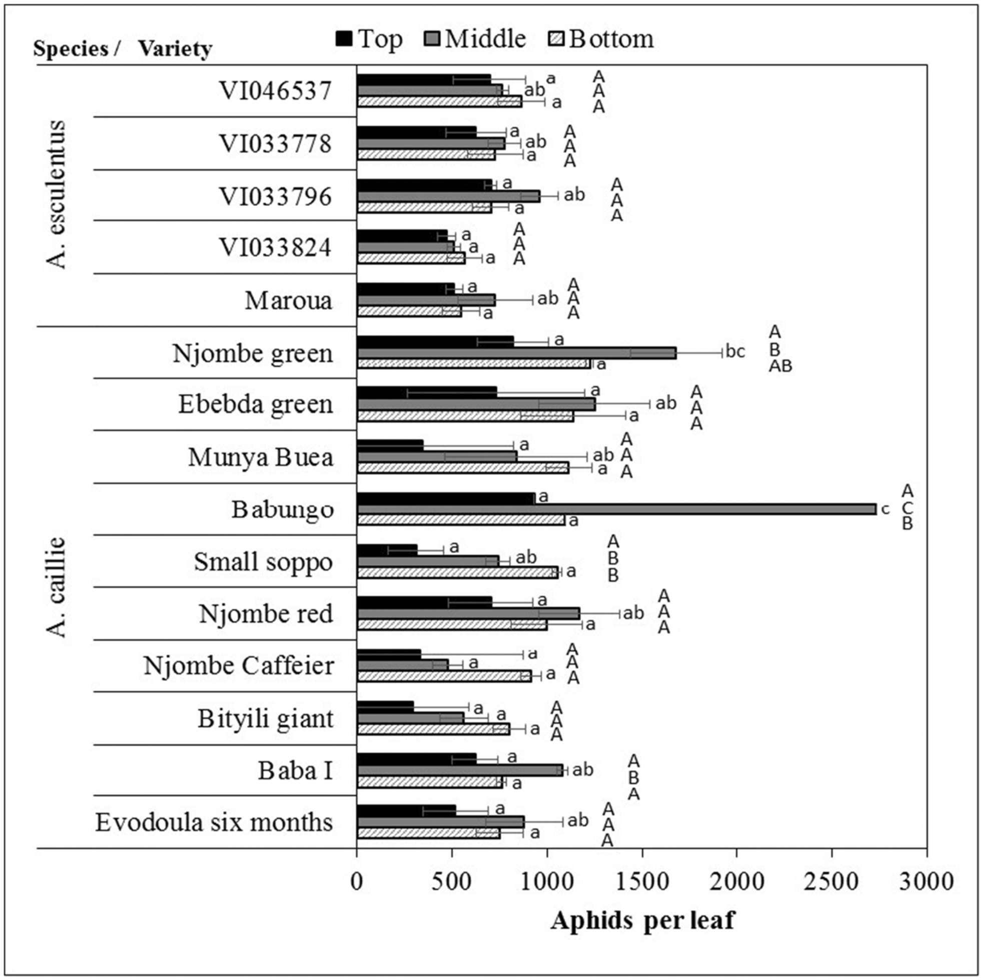

Fig. 4 aphid abundance on bottom, middle and top strata of the various okra verities. For each variety mean values represented by bars with the same upper-case letter(s) are not significantly different; and for each stratum, mean values represented by bars with the same lower-case letter(s) are not significantly different *(Tukey test $\alpha = 0.05$)*

present on okra, but aphids have been one of the most notorious pests of okra and are recurrent among the top pest of vegetables (Abang et al. 2013). The effect of several insect pests on yield of okra has been evaluated. However, Yield losses were observed only when aphid infestation is exceedingly higher (score of 4) (Mohamed-Ahmed 2000; Nderitu et al. 2008). Yield losses can be up to 57% (Shannag et al. 2007). However, these reports did not indicate the okra species studied. In the present study, only one accession (VI033824) was classified as resistant to aphids, but the yield was 75.5% lower that the yield of the highly susceptible variety. In addition, the presence of aphids on all varieties with only VI033824 classified as resistant also suggest that the resistance mechanisms of the okra variety evaluated could be antibiosis and not antixenosis (no none-preference). Only the middle stratum showed significant difference among varieties with all susceptible (highly or moderately) varieties being the most infested at this stratum. Leaf colour, toughness and trichome density can vary with okra stratum and may play a role in antixenosis (Deguine and Hau 2001; Leite et al. 2007; Matthews and Tunstall 1994; Nibouche et al. 2008; Scriber and Feeny 1979). Sarria et al. (2010) likewise did not find aphid antixenosis in cotton; aphids were attracted to settle on all accessions, but the ability to feed and oviposit (Shereen 2007), and to develop and reproduce varied among the accessions. Smith (2005) reported that at times it may be difficult to differentiate between antibiosis and antixenosis as they both adversely affect arthropod populations, and antibiosis may result from antixenosis. Since it was a field experiment with aphid having the choice to infest any variety, it is only a no choice test that can determine whether the mechanism of resistance of VI033824 is Antixenosis,antibiosis or both.

The present study found the yield of *A. caillei* species significantly higher 1.26 ± 0.14 t/ha than *A. esculentus* 0.43 ± 0.08 t/ha. This difference in yield between the species shows that in addition to vigour, in West African okra a considerably longer productive period could enables it to produce more fruits than cultivars of common okra (*A. esculentus*). In the present study, seeds were sown in October and *A. caillei* flowered later (60–100 days) than *A. esculentus* (52–54 days). Days to flowering was at about the lowest limit of the range in a review on *A. esculentus* by Siemonsma and Kouamé (2004) who reported durations of days to flowering as 45–

80 days in the dry season (sowing in October: days shortening) and within 55–105 days after sowing in the rainy season (sowing in March: days lengthening), in southern Côte d'Ivoire. According to another review on *A. caillei* by Siemonsma and Kouamé (2004) West African okra (*A. caillei*) flowers within 50–110 days after sowing in the dry season (sowing in October: days shortening) and within 65–270 days after sowing in the rainy season (sowing in March: days lengthening). Result from the current study (60–100 days) fit well within their range. The slight difference could be attributed to the fact that their report was based on data from Ivory Coast at latitude 5°N, using both local and improved varieties, which might not be the same as in Cameroon (latitude 3°N) where the current study was conducted. Our results also corroborate the findings of Ijoyah (2010) that days to flowering in okra were 66 and 67 days for two consecutive years. However, his results were based on a single variety. Pure culture is a common characteristic of commercial okra growers and prefers improved varieties that are homogeneous and mature early. In subsistence agriculture, okra is grown in home gardens and usually intercropped with other food crops. In West and Central Africa, the local varieties called landraces are usually a mixture of the two species of okra. In dryer areas, *A. esculentus* predominates, while in humid climates, *A. caillei* is mostly found. *A. esculentus* is a short-day plant but has a wide range of geographic distribution up to latitude 40°N. This shows the extent to which the sensitivity of its varieties could differ. Many local varieties of *A. callei* show both qualitative and quantitative short-day responses, even at latitude 5°N. It is therefore not advisable to grown West African okra beyond latitudes 12°N and 12°S in semi-arid and arid zones because of day length sensitivity. Short-day types, planted in March, may not flower by the end of the rainy season in November. They become vegetatively vigorous developed and survive the dry season, and bear fruit hence the name 'late okra' or 'dry-season okra'. The cropping cycle will vary according to variety, location and season between 4 to 12 months (Siemonsma and Kouamé 2004). On the contrary, according to a series of crop specific biology document of the department of biotechnology at the ministry of science and technology of India; *A. esculentus* has crop duration of about 3 months (90–100 days) and rarely reaches 6 months (Siemonsma and Kouamé 2004). These findings are confirmed in the current study where three varieties of *A. esculentus* stopped production at 3 months and two were able to reach 4 months. All the *A. caillei* varieties extended their production period to about four and a half-month except for Ebebda green with crop duration of about 4 months. A comparison of cultivars having similar durations, it is obseved that West African okra has a considerably longer productive period than common okra. This is an attractive feature for home garden planting. On the other hand, *A. esculentus* (common okra) may flower early, but with a shorter productive period is suitable for market gardening. Apart from differences in species and cultivars, okra flowering date may be determined by season and germination date. Germination is controlled by genes, which are affected by environmental factors, such as light, temperature and seed storage conditions (Koornneef et al. 2002). In some cultivars, the occurrence of hard seeds is common and affected by the length of seeds in the pods (Purquerio et al. 2010). Hard seed coats may retard or completely prevent germination by reducing or stopping water uptake by seeds through seed coat and subsequent radicle emergence and gaseous exchange (Mmolawa 1987). During this study, some accession that have been earmarked for difficulties in germinations were induced by mechanical wounding followed by imbibition with 0.05% Gibberelic acid (Ga3).

Differences in aphid infestation on Okra accessions have been demonstrated in this study, with accession VI033824 from AVRDC being the most resistant. Resistant accessions produce less yield, but susceptible farmers' accessions are high yielding. Longer growth cycle may translate into higher yield. *A. caillei* is more vigorous thus able to harbour higher aphid population than *A. esculentus*. The plant vigour overcompensates for aphid feeding injury through a mechanism of tolerance indicated by higher yields. While efforts are needed to determine whether resistance observed with VI033824 is due to antibiosis or antixenosis, it could be incorporated into an integrated pest management strategy to reduce aphid load permitting less chemical spray to control aphids on okra. VI033824 and other *A. esculentus* can also serve in breeding activities to improve farmers' okra varieties in aphid resistance and reduce the length of growth cycle. High yield trait in farmers' varieties such as Babungo, Njombe red, Evodoula 6 months and Small Soppo and other *A. caillei* species can be exploited in breeding programs as useful mechanism of tolerance to aphids. Further studies need to be carried out on these varieties in other to determine certain genetic factors that may have triggered their performance. *A. caillei* can be recommended for home gardening. *A. esculentus* (common okra) with a shorter productive period is suitable for market gardening.

Acknowledgements We thank the Federal Ministry for Economic Cooperation and Development, Germany for financing this study and the collaboration of the University of Yaoundé I, Cameroon.

Funding information International Institute of Tropical Agriculture (IITA) [grant number 81132671] from Federal Ministry for Economic Cooperation and Development, Germany.

Compliance with ethical standards

Conflict of interest No potential conflict of interest was reported by the authors.

References

Abang AF (2018) Interactions between the germplasm of okra (*Abelmoschus* spp.) and aphids with special reference to *Aphis gossypii* glover (Hemiptera: Aphididae) in Cameroon. Thesis presented in partial fulfilment of the requirements for the award of PhD in biology of animal organism, University of Yaoundé 1, Cameroon

Abang AF, Kouame CM, Abang M, Hanna R, Fotso AK (2013) Vegetable growers' perception of pesticide use practices, cost, and health effects in the tropical region of Cameroon. Int J Agron Plant Prod 4:873–883

Abang AF, Kouamé CM, Abang M, Hanna R, Fotso AK (2014) Assessing vegetable farmer knowledge of diseases and insect pests of vegetable and management practices under tropical conditions. Int J Veg Sci 20:240–253. https://doi.org/10.1080/19315260.2013.800625

Ajayi OC (2005) Biological capital, user costs and the productivity of insecticides in cotton farming systems in sub-Saharan Africa. Int J Agric Sustain 3:154–166

Anitha KRS, Nandihalli B (2009) Evaluation of some okra hybrids against leaf hopper and aphid. Karnataka J Agric Sci 22:718–719

Asawalam EF, Emeasor KC, Adieze O (2007) Influence of some soil amendments on insect pest infestation and damage to okra *Abelmoschus esculentus* (L.) Moench in Umudike, Abia State. Res J Biol Sci 2:108–111

Avallone S, Tiemtore TWE, Rivier CM, Treche S (2008) Nutritional value of six multi ingredient sauces from Burkina Faso. J Food Compos Anal 21:553–558

AVRDC (Asian Vegetable Research and Development Center) (1979) Progress report for 1978. Shanhua, Taiwan, Republic of China

Belmain SR, Haggar J, Holt J, Stevenson PC (2013) Managing legume pests in sub-Saharan Africa. In: challenges and prospects for improving food security and nutrition through agroecological intensification. Natural Resources Institute, University of Greenwich, p 34

Chabi-Olaye A, Nolte C, Schulthess F, Borgemeister C (2005) Effects of grain legumes and cover crops on maize yield and plant damage by *Busseola fusca* (fuller) (Lepidoptera: Noctuidae) in the humid forest of southern Cameroon. Agric Ecosyst Environ 108:17–28

Deguine JP, Hau B (2001) The influence of the plant on Aphis gossypii. Some results of research conducted in Cameroon. In: Gourlot, J-P and Frydrych, R. (eds), Improvement of the marketability of cotton produced in zones affected by stickiness: project CFC/ICAC/11. CFC, CIRAD-CA-COTON, IFTH, SCC, ARC. Amsterdam: CFC, 1 cd-rom CIRAD-CA, cotton program, TA 72/09, 34398 Montpellier Cedex 5, France. Pp. 86-98

Djiéto-Lordon C, Aléné DC, Reboul JL (2007) Contribution à la connaissance des insectes associés aux cultures maraîchères dans les environs de Yaoundé – Cameroun. Cameroon J Biol Biochem Sci 15:1–13

Dogimont C, Bendahmane A, Chovelon V, Boissot N (2010) Host plant resistance to aphids in cultivated crops: genetic and molecular bases, and interactions with aphid populations. C R Biol 333:566–573

Ellis-Jones J, Stenhouse J, Gridley H, Hella J, Onim M (2008) Vegetable breeding and seed Systems for Poverty Reduction in Africa. Baseline Study on Vegetable Production and Marketing. Cameroon vBSS Baseline Synthesis Report - final draft

FAO (2015) Food and agricultural Organization of the United Nations. FAO's corporate database. http://faostat3.fao.org/browse/Q/QC/E (last accessed 11 Mar 2016)

Horber E (1980) Types and classification of resistance. In: Maxwell FG, Jennings PR (eds) Breeding plants resistant to insects. John Wiley and Sons, New York, pp 15–21

Hughes J (2009) Just famine foods? What contribution can underutilized plants make to food security? Acta Hortic 806(1):39–47

Ijoyah MO (2010) Productivity of okra (Abelmoschus esculentusL. Moench) at varying sowing dates in Makurdi, Nigeria. J Appl Biosci 32:2015–2019

Kekeunou S, Messi J, Weise S, Tindo M (2006) Insect pests' incidence and variations due to forest landscape degradation in the humid forest zone of southern Cameroon: farmers' perception and need for adopting an integrated pest management strategy. Afr J Biotechnol 5:555–562

Kendall CWC, Jenkins DJA (2004) A dietary portfolio: maximal reduction of low-density lipoprotein cholesterol with diet. Curr Atheroscler Rep 6:492–498

Kessler A, Baldwin IT (2001) Defensive function of herbivore-induced plant volatile emissions in nature. Science 291:2141–2144

Koch KG, Chapman K, Louis J, Heng-Moss T, Sarath G (2016) Plant tolerance: a unique approach to control hemipteran pests. Front Plant Sci 7:1–12

Kogan M, Ortman EE (1978) Antixenosis-a new term proposed to replace Painter's "non-preference" modality of resistance. Bull Entomol Soc Am 24:175–176

Kogan M, Paxton J (1983) Natural inducers of plant resistance to insects. In: Hedin P.A. (ed.), Plant Resistance to Insects. Am. Chem. Soc. Symp. Series 208. Washington, DC: American Chemical Society, pp. 153–171

Koornneef M, Bentsink L, Hilhorst H (2002) Seed dormancy and germination. Curr Opin Plant Biol 5:3336

Kumar S, Dagnoko S, Haougui A, Ratnadass A, Pasternak D, Kouame C (2010) Okra (Abelmoschus spp.) in west and Central Africa: potential and progress on its improvement. Afr J Agric Res 5:3590–3598

Leite GL, Picanco DM, Zanuncio JC, Gusmao MR (2007) Factors affecting colonization and abundance of *Aphis gossypii* glover (Hemiptera: Aphididae) on okra plantations. Ciência e Agrotecnologia, Lavras 31: 337–343

Manach C, Williamson G, Morand C, Scalbert A, Remesy C (2005) Bioavailability and bioefficacy of polyphenols in humans. I. Review of 97 bioavailability studies. Am J Clin Nutr 81(1):230–242

Matthews GA, Tunstall JP (1994) Insect pests of cotton. CAB International, Wallingford xii + 593 pp

Metcalf RL, Luckman WH (1994) Introduction to insect pest management, 3rd edn. John Wiley Sons, Inc., New York, 137 pp

Mmolawa OB (1987) Germination and dormancy of meadow foam seed. M.Sc. thesis, Oregon State University, USA

Mohamed-Ahmed MM (2000) Studies on the control of insect pests in vegetables (okra, tomato, and onion) in Sudan with special reference to neem preparations. PhD dissertation, University of Giessen, Germany. 123 pp.

Moyin-Jesu EL (2007) Use of plant residues or improving soil fertility pod nutrients root growth and pod weigth of okra *Abelmoschus esculentum* L. Bioresour Technol 98:2057–2064

NAP (2006) Lost Crops of Africa Volume II: Vegetables pp 287–301. https://www.nap.edu/catalog/11763.html

Ndemah R (1999) Towards developing a sustainable pest management strategy for the African stalk borer, *Busseola fusca* (fuller) (Lepidoptera: Noctuidae) in maize systems of Cameroon. Ph. D. Thesis, Hanover University. 320 pp.

Ndemah R, Schulthess F, Korie S, Borgemeister C, Poehling M, Cardwell K (2003) Factors affecting infestation of the stalk borer *Busseola fusca* (Lepidoptera: Noctuidae) on maize in the forest zone of Cameroon with special reference to Scelionid egg parasitoids. Environ Entomol 32:51–60

Nderitu JH, Kasina JM, Kimenju JW, Malenge F (2008) Evaluation of synthetic and neem-based insecticide for managing aphids on okra (Malvaceae) in eastern Kenya. J Entomol 5:207–212

Nibouche S, Brevault T, Klassou C, Dessauw D, Hau B (2008) Assessment of the resistance of cotton germplasm (*Gossypium* spp.) to aphids (Homoptera: Aphididae) and leafhooper

(Homoptera: Cicadellidae): methodology and genetic variability. Plant Breed 127:376–382
Ojo J (2016) Pesticides use and health in Nigeria. IFE J Sci 18(4):981–991
Painter RH (1951) Insect resistance in crop plants. The Macmillan Co., New York, pp 24–25
Pearce G, Styrdom D, Johnson S, Ryan CA (1991) A polypeptide from tomato leaves induces wound-inducible proteinase inhibitor proteins. Science 253:895–898
Purquerio V, Luis F, Antonio A, Francisco A (2010) Germination and hardseedness of sedes in okra elite lines. Hortic Bras 28:232–235
Rosenthal JP, Kotanen PM (1994) Rosenthal J, Kotanen P. terrestrial plant tolerance to herbivory. Trends Ecol Evol 9:145–148
Sarria E, Palomares-Rius FJ, López-Sesé AI, Heredia A, Gómez-Guillamón ML (2010) Role of leaf glandular trichomes of melon plants in deterrence of *Aphis gossypii* glover. Plant Biol 12:503–511
Schippers RR (2000) African indigenous vegetables. An overview of the cultural species. Natural Resources Institute/ACP-EU Technical Centre for Agricultural and Rural Cooperation, Chatham 214pp
Scriber JM, Feeny P (1979) Growth of herbivorous caterpillars in relation to feeding specialisation and to the growth form of their host plants. Ecology 60:829–850
Shaner G, Finney RE (1977) The effect of nitrogen fertilization on the expression of slow-mildewing resistance in Knox wheat. Phytopathology 67:1051–1056
Shannag HK, Al-Qudah JM, Makhadmehi M, Freihat NM (2007) Differences in growth and yield responses to Aphis gossypii glover between different okra varieties. Plant Prot Sci 43:109–116
Shereen ME (2007) Insect interactions of three trophic levels on milkweed plant, *Asclepias sinaica* (Boiss) Musch. Int J Agric Biol 9:292–293
Siemonsma JS (1982) West-African okra - morphological and cytogenetical indications for the existence of a natural amphidiploid of Abelmoschus esculentus (L.) Moench and A. manihot (L.) Medikus. Euphytica 31:241–252
Siemonsma JS, Kouamé C (2004) *Abelmoschus esculentus* (L.) Moench. Internet record from Protabase. Grubben GJH, Denton OA (eds.), PROTA (plant resources of tropical Africa, Wageningen, Netherlands. http://database.prota.org/search.htm
Smith CM (1989) Plant resistance to insects: A fundamental approach. Wiley Sons, Inc., New York, 294 pp
Smith CM (2005) Plant resistance to arthropods. Springer, Dordrecht
Strauss SY, Agrawal AA (1999) Strauss S, Agrawal A. the ecology and evolution of plant tolerance to herbivory. Trends Ecol Evol 14:179–185
Sumathi E (2005) Screening of okra germplasms for their relative resistance to aphid and leafhopper damage. J Ecobiol 17:451–454
Tabacian H, Ravan S, Bandani AR (2011) Susceptibilities of two populations of *Aphis gossypii* glover to selected insecticides. Afr J Biotechnol 10:670–674
Wanja EW, Hallett RH, Sears MK, Sithanantham S (2001) Insect pest constraints of okra, *Abelmoschus esculentus*(L.) Moench (Malvaceae), in Kenya. In: ESA 2001 Annual meeting – 2001: an entomological odyssey of ESA, San Diego
Wratten SD, Gurr GM, Tylianakis JM, Robinson KA (2007) Cultural Control. In: van Emden HF, Harrington R (eds) Aphids as crop pests. CAB International, Reading, pp 423–445
Zarpas KD, Margaritopoulos JT, Stathi L, Tsitsipis JA (2006) Performance of cotton aphid *Aphis gossypii* (Hemiptera: Aphididae) lineages on cotton varieties. Int J Pest Manag 52:225–232