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Screening for resistance to cowpea aphids (Aphis craccivora Koch.) In mutation derived and cultivated cowpea (Vigna unguiculata L. Walp.) genotypes

Aaron Chimbelya Siyunda, Natasha Mwila, Mick Mwala, Kalaluka Munyinda, Kelvin Kamfwa, Gilson Chipabika & Dyness Nshimbi

Abstract

Research studies aimed at screening cowpea genotypes against *Aphis craccivora* K. commonly known as black aphids, under the no-choice infestation condition, were conducted in the greenhouse at Natural Resource Development College (NRDC), Lusaka, Zambia in 2021. The main objective was to discern the cowpea genotype that is resistant to *Aphis craccivora* K that would aid the reduction of yield losses encountered in cowpea production. The most resistant genotype BBBT1-11 across all parameters investigated recorded an average aphid score of 1.0, compared to LT11-3-3-12 which recorded the highest score of 7.0. The aphid population build-up of BBBT1-11 was 1.0 compared to the highest recorded by LT11-5-1-1-4 at 3.54. The highest plant vigour of 3.0 was recorded by BBBT1-11, BB10-4-3-2, and LT11-5-1-1-4, and the lowest was recorded by Sanzi (1.2). BBBT1-11 recorded a survival percentage of 100% at 21DAI compared to the lowest recorded by TVu 2027 (20%). Mutant line BBBT1-11 emerged as a resistant genotype across all parameters tested including weight of seeds/plant and amount of seeds/plant. BBBT1-11 could further be assessed for the possible presence of biochemicals and traits, that could explain the basis of the observed differences among the genotypes in their reaction to *Aphis craccivora* K. Besides, BBBT1-11 can also be incorporated in the breeding program with the target of breeding cowpea varieties that are resistant to aphid infestation to address the yield losses experienced in cowpea production as a result of A. craccivora K.

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About Author (s)

Aaron Chimbelya Siyunda (Corresponding Author)**,** Department of Crop Science, Natural Resources Development College (NRDC), Lusaka, Zambia.

Natasha Mwila, Department of Plant Science, School of Agricultural Science, University of Zambia (UNZA), Lusaka, Zambia.

Mick Mwala, Department of Plant Science, School of Agricultural Science, University of Zambia (UNZA), Lusaka, Zambia.

Kalaluka Munyinda, Department of Plant Science, School of Agricultural Science, University of Zambia (UNZA), Lusaka, Zambia.

Kelvin Kamfwa, Department of Plant Science, School of Agricultural Science, University of Zambia (UNZA), Lusaka, Zambia.

Gilson Chipabika, Department of Plant Science, School of Agricultural Science, University of Zambia (UNZA), Lusaka, Zambia.

Dyness Nshimbi, Department of Crop Science, Natural Resources Development College (NRDC), Lusaka, Zambia.

Introduction

Cowpea (*Vigna unguiculata* L. Walp) is an annual legume, mostly cultivated and considered important cash and nutritional security grain legume in the semi-arid regions of sub-Saharan Africa (Asiwe, 2009; Kusi et al., 2010; Souleymane et al., 2013; and Ouedraogo et al., 2018). It is an important component of cropping systems in the Semi-arid regions covering part of the Middle East, Asia and Oceania, Africa, Southern Europe, and central and south America (Singh et al., 2002). However, grain yield in cowpea production remains low, rarely exceeding 500 kg per ha in the traditional production system (Langyintuo et al.,2003; Ouedraogo et al., 2018). Cowpea production is affected by several biotic stress factors, which includes several insect pests that damage the crop by infesting it at all developmental stages, in the field as well as at postharvest. Cowpea aphid, *A. craccivora* Koch (Hemiptera: Aphididae), is one of the main insect pests that affect cowpea production (Berberet et al., 2009; Radha, 2013; Huynh et al., 2015; and Lourenco et al., 2018). Besides causing direct damage by sucking sap, *A. craccivora* K is also responsible for the transmission of a wide range of viruses i.e., cucumber mosaic virus (CMV), cowpea severe mosaic virus (CPSMV), cowpea aphid-borne mosaic virus (CABMV) etc. (Thottapilly et al., 1990; Blackman and Eastop, 2000; Oliveira et al., 2012; Freitas et al., 2012 and Lourenco et al., 2018). Singh and Allen (1980) cited by Souleymane et al, (2013) have reported several insecticides which have proved to be effective against aphids, but insecticides are often not accessible to small-scale farmers who are mostly involved in cowpea production. The use of resistant varieties offers the best option to small-scale farmers owing to its low cost (Dent, 1991). Host Plant Resistance is an efficient, cheap and environmentally friendly way of controlling *A. craccivora* in an integrated control system. Different cowpea genotypes have been screened and different levels of resistance to aphids have been identified (Kusi et al., 2010; Aliyu and Ishiyaku, 2013; and Ouedraogo et al., 2018). However, resistance to aphids (*A. craccivora* K.) of most of the identified cowpea cultivars at IITA has recently broken down (Fatokun personal correspondence) as cited by Souleymane et al., (2013). Thus, there is a need to identify new sources of resistance to *A. craccivora*. The main objective of the current study was to identify cowpea cultivars with resistance to *A. craccivora* as a way of contributing to the improvement of cowpea productivity.

Materials and Methods

The study was conducted in the greenhouse at Natural Resource Development College (NRDC), Lusaka, Zambia in 2021. The materials consisted of 21 cowpea genotypes advanced from the open field screening method. These 21 that exhibited the resistant trait during the open field screening method were selected from an initial set of 110 genotypes and thus were advanced to validate their resistance. The cowpea genotypes evaluated included 1 landrace variety from Zambia Agriculture Research Institute (ZARI), 2 mutation derived cultivated varieties, and 15 advanced mutation derived varieties (at 9th mutation generation) from the University of Zambia, School of Agricultural Sciences, Plant Science Department under the Cowpea Mutation Breeding Project, and 3 pureline genotypes from the International Institute of Tropical Agriculture (IITA). The aphids used for this study were collected from the University of Zambia field station, during the open field screening of cowpea genotypes. The aphids were maintained on a susceptible cowpea cultivar TVx 3236, in the greenhouse using the insect-proof cage away from parasites and/or other predators at Natural Resources Development College (NRDC), Zambia. The experimental design used in the present study was a Completely Randomized Design (CRD) with 3 replications (Steel and Torrie, 1980). Seeds of 21 cowpea genotypes were sown on July 28, 2021, in plastic polyethene pots filled with sterilized topsoil and kept in insect-proof cages with fine mesh, small enough to allow passage of air but not insects. Each pot contained three plants of the same accession. Seven days after planting, each seedling was infested with five aphids, this was done by placing them with a camel hair brush (Lourenco et al., 2018). The pots remained in the insect-proof cages for 21 days after infestation during which the plants were assessed using different variables. Dead plants were regarded as susceptible while those still alive, with first trifoliate leaves developing, as resistant (Soulemane et al, 2013; Lourenco et al., 2018). The variables collected from this study were aphid score, aphid population build-up, plant vigour scores, and plant survival rate. The number of insects was counted using a visual score of 1 to 9, where 1 =0-4 aphids, 3=5-20 aphids, 5=21- 100 aphids, 7= 101-500 aphids and 9= >500 (high aphid colonisation and plant death) (Obopile, 2006; and Soulemane et al, 2013). Plant vigour scores were calculated using a scale of 1-3, where 1 denotes senescence (weak), 2 indicates medium growth and 3 denotes survival (more vigorous) (Obopile, 2006). Aphid population build-up rating score was calculated using a scale of 0 to 5, where 0=no aphids, 1= a few individual aphids, 2= few small individual colonies, 3= several small colonies, 4=large individual colonies and 5= large continuous colonies. (Obopile, 2006; and Soulemane et al, 2013). Aphid score (Aphids per plant), Aphid population build-up, plant vigour and plant survival rate were counted at 5, 9, 13, 17 and 21 days after infestation. Plants that survived aphid infestations were allowed to grow and produce seeds (Soulemane et al, 2013).

Data Analysis

The data collected from the study were subjected to analyses of variance (ANOVA) for the test of significance at 5%. An average number of aphids per accession was calculated and the mean level of infestation scores of each accession was determined. Variables that display significant differences were separated using Turkey's HSD test. Treatment means were considered significant when $P \leq 0.05$ at the 5% level.

Results and Discussion

Average Aphid Score

Table 1 presents the average aphid score for the genotypes at different intervals as defined by Day After Infestation (DAI). The cowpea genotypes showed significant differences from each other at a 5% level of significance, in terms of the number of aphids per plant. The cowpea lines LT4-2-4-1-1, LT11-3-3-12 and Sanzi, recorded the highest aphid score of 4.3 at 5 DAI. These lines were not significantly different from cowpea lines; Lunkwakwa (3.7), LT 11-5-1-1-4 (3.7), TVu 2027 (3.0), Namuseba (3.0), BB7-9-7-5-1 (3.0) and BB7-9-7-5-4 (3.7), Lukusuzi (3.7), BB10-4-2-3-1 (3.0) and BB10-4-2-3-3 (3.0), LT3-8-4-1 d (3.0), and MS 1-8-2-6-8 (3.0). The cowpea line BB10-4-2-3-2 recorded the lowest aphid score of 1.0 which was at par with BBBT1-11, BBBT1-5 and LTBT1-5 with aphid scores of 1.7, 2.3 and 2.3 respectively. At 9, 13, 17, and 21 DAI, cowpea line BB10-4-2-3-2 recorded the lowest aphid scores of 1.0, 1.0, 1.0 and 0.7 respectively. However, the lower aphid scores recorded by BB10-4-2-3-2 were not significantly different from the aphid score of BBBT1-11 on 13(1.7), 17(1.0) and 21(1.0) DAI and also for Namuseba (1.0) and BB10-4-2-3-1(1.7) on 21 DAI. At 9 DAI, cowpea lines LT4-2-4-1-1, LT4-2-4-1-2, Lukusuzi and LT11-5-1-1-4 had the highest aphid score of 7.0 which was significantly different at 5% level of significance, from BB10-4-2-3-2 (1.0), BBBT1-11 (1.7), BBBT1-5 (2.3) and LTBT1-5 (2.3). On 13, 17 and 21 DAI, LT11-3-3-12 recorded the highest aphid scores of 7.0, 9.0 and 9.0 respectively. The multiplication of aphids on cowpea lines that showed susceptibility and those that showed tolerance was rapid and plants were fully colonized within four to nine days after infestation. Significant differences at a 5% level of significance, occurred at 5 DAI and onwards for the cowpea lines. The findings are consistent with Arturo et al (1988), in which the researcher reported significant differences in the cumulative number of progenies per aphid female on the fourth day and onwards in a cross between the susceptible line and the two resistant lines. Ofuya (1993) and Souleymane et al (2013), also reported significant differences in the number of aphids in susceptible and resistant varieties. The leaves of cowpea lines that showed susceptibility in the present study turned yellow, became stunted and started dying at 9 DAI onwards, this agrees with Bata et al (1987) and Souleymane et al (2013). The present study had genotypes (28.6%) that indicated tolerance against aphids, this is in conformity with Souleymane et al (2013), who also reported the genotype IT97K-556-6 having levels of tolerance as it withstood the aphid pressure. The constant resistance observed in the cowpea lines BBBT1-11 and BB10-4-2-3-2, may be due to resistance which is expressed through antibiosis and antixenosis compounds that can disturb the functioning of aphids, and also the growth and development of aphids (Arturo et al., 1988; Teetes, 2007; Smith and Clement, 2012; Alabi et al., 2012; and Omoigul et al., 2017). Therefore, cowpea lines BBBT1-11 and BB10-4-2-3-2 suggest high levels of antixenosis and antibiosis. These lines were the least favourable/susceptible to aphid infestation and LT11-3-3-12 was the most favourable/susceptible. According to Teetes (2007) as cited in Ouedraogo et al, (2018), stated that antixenosis and antibiosis activities often result in the rise in insect mortality or reduced longevity and reproduction of most insects.

Table 1: Average Aphid Score in Cowpea genotypes

Genotype	Days After Infestation (DAI)				
	5	**9**	**13**	**17**	**21**
BBBT 1-11	1.7	3.0	1.7	1.0	1.0
BB10-4-2-3-2	1.0	1.0	1.0	1.0	1.0
Namuseba	3.0	3.7	3.7	3.0	1.0
BB7-9-7-5-4	3.7	5.0	4.3	3.0	3.0
BB10-4-2-3-1	3.0	4.3	3.7	3.0	1.7
Lukusuzi	3.7	7.0	7.0	5.7	3.7
BB7-9-7-5-1	3.0	6.3	6.3	5.0	4.3
LT4-2-4-1-2	3.0	7.0	6.3	5.0	5.0
MS1-8-2-6-8	3.0	6.3	6.3	5.0	5.0
BBBT1-7	3.0	5.0	7.0	5.7	5.0
LTBT1-5	2.3	5.7	6.3	5.0	5.0
LT3-8-4-1-4	3.0	5.0	7.0	7.0	5.7
BB10-4-2-3-3	3.0	5.0	6.3	5.7	5.0
IT07K205-8	3.0	5.0	5.7	7.7	4.3
BBBT1-5	2.3	5.0	7.0	5.7	5.0
TVU 2027	3.0	5.0	5.0	5.0	3.7
LT11-5-1-1-4	3.7	7.0	5.7	7.7	7.7
Lunkwakwa	3.7	5.7	6.3	5.0	5.0
Sanzi	4.3	5.7	5.7	7.0	7.0
LT11-3-3-12	4.3	5.7	7.0	9.0	9.0
LT4-2-4-1-1	4.3	7.0	6.3	7.7	7.0
S. Em ±	0.12	1.01	0.88	0.23	1.44
CD at 5%	1.33	1.39	1.88	1.49	1.68
CV%	2.01	1.73	3.21	4.11	3.98

Aphid Population Build-up Score

Table 2, presents the rate of aphid population build-up on seedlings of cowpea genotypes. Aphid population build-up was very rapid and the plants were fully colonized within 7 to 9 days after infestation (DAI). At 5 DAI, there were fewer differences in terms of aphid population build-up among cowpea lines. 12 cowpea lines recorded the lowest aphid population build-up score of 1.0 at 5 DAI, this included cowpea lines; BBBT 1-11, BBBT1-5, BB10-4-2-3-1, BB10-4-2-3-2, and BB10-4-2-3-3, BB7-9-7-5-1, LT4-2-4-1-2, MS1-8-2-6-8, LTBT1-5, LT3-8-4-1-4, and IT07K205-8. However, these cowpea lines differed significantly from cowpea lines LT11-3-3-12 and LT11-5-1-1-4 which had the highest score of 2.0. Nevertheless, LT11-3-3-12 and LT11-

5-1-1-4 recorded the aphid population build-up score, not significantly different at a 5% level of significance from the score of cowpea lines BBBT1-7, Lunkwakwa and Sanzi that recorded 1.5, 1.7 and 1.7 respectively. At 9, 13, 17, and 21 DAI, cowpea lines BBBT1-11, BB10-4-2-3-1, BB10-4-2-3-2, and Namuseba recorded the lowest scores that were not significantly different. At 9 DAI, the highest score was recorded by cowpea line LT4-2-4-1-2 with a score of 4.0, at 13 DAI the highest score was recorded by Lukusuzi with a score of 4.0, and at 17 the highest score was recorded by LT3-8-4-1-4 with the score of 4.0 and lastly at 21 DAI, LT11-5-1-1-4 recorded the highest score of 4.7. It is worth acknowledging, that differences were significantly increasing as DAI was increasing. A high score of aphid population build-up was observed between 9 and 13 DAI. However, between 13 and 21 DAI, the aphid population build-up rate was lower than that between 9 and 13 days. Cowpea line LT 11-5-1-1-4, unlike other cowpea lines that showed a decreasing trend in aphid population build-up after the 13th day from infestation, this line showed an increasing trend in the aphid population build-up score and recorded its highest score at 21 DAI. In the present study, cowpea lines BBBT1-11, BB10-4-2-3-1, BB10-4-2-3-2, and Namuseba recorded the lowest scores of aphid population build-up consistently, which was not significantly different at the 5% level of significance. These lines may be classified as resistant varieties against *A. craccivora* as indicated by Giga (2001), who stated that resistance to aphid attack can be characterized by an isolated and lower insect population density. As observed in the current study, differences in the spread of aphid colonies and variations in the insect population density on different cowpea lines may be attributed to varying levels of sweetness of different cowpea lines (Arturo et al.,1998). That is, without antixenosis and antibiotic compounds in the plant tissues that can disturb the functioning of aphids, and also growth and development (Arturo et al., 1988; Teetes, 2007; Smith and Clement, 2011; Alabi et al., 2012; and Omoigul et al., 2017).

Table 2: Aphid Population Build-up Score in Cowpea genotypes

	Days After Infestation (DAI)				
Genotype	**5**	**9**	**13**	**17**	**21**
BBBT 1-11	1.0	1.7	1.0	1.0	0.3
BB10-4-2-3-2	1.0	1.0	1.0	1.0	0.7
Namuseba	1.0	1.3	1.0	1.0	1.0
BB7-9-7-5-4	1.3	2.7	2.0	2.3	1.3
BB10-4-2-3-1	1.0	1.7	1.7	1.0	1.0
Lukusuzi	1.3	4.0	4.0	3.3	1.3
BB7-9-7-5-1	1.0	3.7	3.7	3.0	2.0
LT4-2-4-1-2	1.0	4.0	3.7	3.0	2.7
MS1-8-2-6-8	1.0	3.7	3.7	3.0	2.7
BBBT1-7	1.5	3.0	4.0	2.5	2.5
LTBT1-5	1.0	3.3	3.7	3.0	2.0
LT3-8-4-1-4	1.0	3.0	4.0	4.0	2.7
BB10-4-2-3-3	1.0	3.0	3.7	3.0	2.3
IT07K205-8	1.0	2.7	3.7	3.7	2.3
BBBT1-5	1.0	2.3	4.0	3.0	2.0
TVU 2027	1.7	3.0	3.0	2.3	1.7
LT11-5-1-1-4	2.0	3.0	4.0	4.0	4.7
Lunkwakwa	1.7	2.7	3.7	2.7	2.7
Sanzi	1.7	2.7	3.7	3.3	2.3
LT11-3-3-12	2.0	3.0	4.0	4.0	3.3
LT4-2-4-1-1	1.3	2.7	3.7	3.7	3.3
S. Em ±	0.2	1.1	0.8	1.2	1.1
CD at 5%	0.6	0.8	0.9	0.9	1.1
CV%	0.9	1.2	2.1	1.4	2.9

Plant Vigour Analysis at 21 DAI

Table 3 presents the results obtained, showing that the plant vigour of different cowpea varieties was significantly different (P<0.05). Cowpea lines BBBT1-11, BB10-4-2-3-2, and LT11-5-1-1-4 scored the highest plant vigour of 3.0. Though not significantly different from cowpea lines BB10-4-2-3-1(2.3), Namuseba (2.3) and LTBT1-5 (2.7). Cowpea line BBBT1-7 recorded the lowest score of 1.0. However, BBBT1-7 was not significantly different at 5% level of significance, from cowpea lines LT4-2-4-1-1(1.3) and LT4-2-4-1-2(1.7), LT11-3-3-12(1.7), Sanzi (1.2), TVU 2027(1.3), BBBT1-5 (1.3), IT07K205-8(1.3), LT3-8-4-1-4(1.7). Unlike other cowpea lines that recorded a lower score of aphids per line, cowpea line LT11-5-1-1-4 recorded a significant high aphid score of 7.7 at 21DAI but yet its plant vigour score was 3 (vigorous growth). Nine cowpea lines out of twenty-one lines showed low performance (poor growth) and six cowpea lines indicated medium promising vigour. The remaining six cowpea lines out of twenty-one lines showed good performance. Thus, the cowpea lines with medium to good performance, according to Arturo (1988), managed to tolerate the severity of an aphid attack. The present findings are also supported by the findings of Giga (2001) who reported that resistant varieties can grow vigorously with no or fewer damage symptoms compared to susceptible varieties, regardless of the insect pressure/infestation. Singh et al (1996), further stated that resistance in plants, can be seen by the development of new leaves (trifoliate) even under attack and thus the crop continues to flower and form pods.

Table 3: Plant Vigour Analysis at 21 DAI in Cowpea genotypes

Genotype	Average Score
BBBT 1-11	3.0
BB10-4-2-3-2	3.0
Namuseba	2.3
BB7-9-7-5-4	2.0
BB10-4-2-3-1	2.3
Lukusuzi	2.0
BB7-9-7-5-1	2.0
LT4-2-4-1-2	1.7
MS1-8-2-6-8	2.0
BBBT1-7	1.0
LTBT1-5	2.7
LT3-8-4-1-4	1.7
BB10-4-2-3-3	2.0
IT07K205-8	1.3
BBBT1-5	1.3
TVU 2027	1.3
LT11-5-1-1-4	3.0
Lunkwakwa	2.0
Sanzi	1.2
LT11-3-3-12	1.7
LT4-2-4-1-1	1.3
S. Em ±	1.1
CD at 5%	1.0
CV%	3.1

Percentage survival of seedlings from 5 to 21 days after infestation

Table 4, indicates that the plant survival rate of different cowpea varieties was not significantly different (P>0.05) at 5 and 9 DAI as shown in Table 5. However, the cowpea lines were significantly different (P<0.05), beginning at 13 DAI to 21 DAI and the trend of significance was progressive. At 21 DAI, TVu 2027 and IT07K205-8 recorded the lowest percentage survival rate of 20 and 44.4 respectively. Cowpea line IT07K205-8 which recorded 44.4 was not significantly different from the mutant lines BBBT1-7 at 50, BB7-9-7-5-4 at 55.5 and MS1-8-2-

6-8 at 62.5. Cowpea lines BBBT1-11, BB10-4-2-3-1, BB10-4-2-3-2, BB7-9-7-5-1, LT4-2-4-1-2, LT11-5-1-1-4 recorded a survival percentage rate of 100%, which is a good indication of tolerance.

Table 4: Plant Survival Rate in Cowpea genotypes

	Days After Infestation (DAI)				
Genotype	**5**	**9**	**13**	**17**	**21**
BBBT 1-11	100	100	100	100	100
BB10-4-2-3-2	100	100	100	100	100
Namuseba	100	100	100	100	87
BB7-9-7-5-4	100	88	88	66	55
BB10-4-2-3-1	100	100	100	100	100
Lukusuzi	100	100	100	87	87
BB7-9-7-5-1	100	100	100	100	100
LT4-2-4-1-2	100	100	100	100	100
MS1-8-2-6-8	100	100	87	87	62
BBBT1-7	100	100	100	100	50
LTBT1-5	100	100	100	100	66
LT3-8-4-1-4	100	100	100	100	87
BB10-4-2-3-3	100	100	100	88	77
IT07K205-8	100	100	77	77	44
BBBT1-5	100	100	100	100	88
TVU 2027	100	100	80	80	20
LT11-5-1-1-4	100	100	100	100	100
Lunkwakwa	100	100	100	100	88
Sanzi	100	100	100	100	88
LT11-3-3-12	100	100	88	77	77
LT4-2-4-1-1	100	100	100	100	77
S. Em ±	0	1.8	3.8	4.7	7.6
CD at 5%	ns	ns	21.9	18.9	19.5
CV%	0	2.9	9.1	12.7	16.4

ns= difference was not statistically significant

The present findings are supported by the study of Ouedraogo et al., (2018), who recorded the lowest average survival percentage of 33% and the degree of infestation equal to 3.6 in the genotype N°2300 and also the highest survival rate of 93.3% and the degree of infestation equal to 1.4 in the genotype IT97K-556-6. A lower average survival percentage may be an indication of susceptibility to aphid attack in cowpea plants, which might be a result of lower levels of antibiosis activities that failed to reduce the development and multiplication of aphids (Teetes, 2007; Alabi et al., 2012; Omoigul et al., 2017). Thus, TVu 2027 and IT07K205-8 exhibited lower levels of antibiosis activities while cowpea lines BBBT1-11, BB10-4-2-3-1, BB10-4-2-3-2, BB7-9-7-5-1, LT4-2-4-1-2, LT11-5-1-1-4 exhibited high levels of antibiosis activities, that enabled the plants to develop new leaves (trifoliate) even under aphid attack (Singh et al, 1996).

Effect of *Aphis craccivora* K. on yield of cowpea genotypes

Table 5, indicates that the number of seeds/plant of different cowpea varieties was significantly different ($P<0.05$). TVu 2027, recorded the lowest amount of seeds/plant of 12 seeds. TVu 2027 was statistically at par with IT07K205-8(20 seeds/plant), and the mutant lines, BB10-4-2-3-3 (31 seeds/plant), BBBT1-5 (33 seeds/plant), LT11-3-3-12 (34 seeds/plant), LT 3-8-4-1-4 (37 seeds/plant), and BBBT1-7 (45 seeds/plant). Cowpea line BBBT1-11 recorded the highest amount of seeds/plant with 235 seeds. BBBT1-11 was followed by BB10-4-2-3-2 (150 seeds/plant). BB10-4-2-3-2 was at par with Namuseba (142 seeds/plant), BB10-4-2-3-1 (120 seeds/plant), LT11-5-1-1-4 (134 seeds/plant), and Lunkwankwa (133 seeds/plant). Table 5, further indicates that the weight of seeds in grams per plant of different cowpea varieties was significantly different (P<0.05). TVu 2027, recorded the lowest weight of seeds/plant at 1.8g/plant. TVu 2027 was statistically at par with IT07K205-8(3.0g/plant), and the mutant lines, BB10-4-2-3-3 (4.2g/plant), BBBT1-5 (3.1g/plant), LT11-3-3-12 (3.6g/plant), LT 3-8-4-1-4 (3.4g/plant), BBBT1-7 (5.3g/plant), LT4-2-4-1-1(6.2/plant), MS1-8-2-6-8 (6.9g/plant), Sanzi (8.2g/plant), and LTBT1-5(4.6g/plant). The mutant line BBBT1-11 (26.8g/plant), outperformed all the cowpea genotypes in terms of weight of seeds in grams per plant.

Table 5: Effects of *Aphis craccivora* K. on yield of cowpea genotypes

Genotype	Number of seeds per plant	Weight of seed (grams/plant)
BBBT 1-11	235	26.8
BB10-4-2-3-2	150	16.7
Namuseba	142	19.7
BB7-9-7-5-4	72	8.9
BB10-4-2-3-1	120	15.2
Lukusuzi	78	11.4
BB7-9-7-5-1	110	12.9
LT4-2-4-1-2	89	12.9
MS1-8-2-6-8	67	6.9
BBBT1-7	45	5.3
LTBT1-5	51	4.6
LT3-8-4-1-4	37	3.4
BB10-4-2-3-3	31	4.2
IT07K205-8	20	3.0
BBBT1-5	33	3.1
TVU 2027	12	1.8
LT11-5-1-1-4	134	17.0
Lunkwakwa	133	18.8
Sanzi	102	8.2
LT11-3-3-12	34	3.6
LT4-2-4-1-1	56	6.2
S. Em ±	3.1	2.5
CD at 5%	38.1	6.5
CV%	4.4	3.3

The findings of the current study are consistent with the findings of Makoi (2019), in which the researcher investigated the effect of disturbing cowpea growth and development concerning cowpea yield and yield components. Any disturbance in cowpea growth and development whether it is a result of biotic or abiotic factors has the potential to affect its yield and yield components negatively (Makoi, 2019). The most negatively affected genotypes by *Aphis craccivora* K. in terms of the number of seeds/plant and weight of seeds/plant were the purelines TVu 2027, and IT07K205-8, and the mutant lines, BB10-4-2-3-3, BBBT1-5, LT11-3-3-12, LT 3-8-4-1-4, and BBBT1-7. This might be because they failed to resist the aphid attack, thus, they may be classified as susceptible. However, Since the mutant line BBBT1-11 was able to withstand the adverse effect of aphids as it had normal yields, this may be indicative of its resistance towards *Aphis craccivora* K. BBBT1-11, BBBT1-5 and BBBT1-7 are mutant lines derived from the same parental genotype named Bubebe. Since significant variations were noticed in the current study with regards to their performance in terms of the effect of *A. craccivora* K on their number of seeds /plant and weight of seeds/plant. This might be due to the genetic variation caused by mutation. This, further indicates that mutation may have successfully manipulated the genome of the genotype Bubebe and resulted in the formation of the resistant gene(s) found in mutant line BBBT1-11 (resistant genotype) and not in mutant lines BBBT1-5 and BBBT1-7.

Relationship between cowpea yield and various parameters

The relationship between the weight of seeds/plant and various growth parameters of *A. craccivora* K. in different cowpea genotypes (Table 6) showed that the weight of seeds/plant had a positive association which was significant with survival rate (r = 0.6**), significant positive association with plant vigour (r = 0.6**), non-significant weak negative association with aphid population build-up (r= - 0.3), significant negative relationship with aphid score (r= -0.5**), and highly significant positive relationship with the number of seeds/plant (r=0.9). The survival rate had a significant positive association with plant vigour (r= 0.5**), a non-significant weak positive association with aphid population build-up (r = 0.1), **), a non-significant weak negative association with aphid score (r = - 0.1), and also a highly significant positive association with number of seeds/plant (r= 0.7**). Plant vigour recorded a non-significant weak negative association with aphid population build-up (r= - 0.1), non-significant negative relationship with aphid score (r= - 0.3), and significant positive relationship with number of seeds/plant (r=0.6). Aphid population build-up had a highly significant positive association with an aphid score (r = 0.8**), and a negative non-significant association with the number of seeds/plant. Aphid score had a significant moderate negative association with the number of seeds/plant.

Table 6: Correlation matrix of various growth parameters of *Aphis craccivora* K. and its effect on cowpea genotypes

Parameters	WSPP	SR	PV	APBP	AS	NSPP
WSPP	-	0.6**	0.6**	-0.3^{ns}	-0.5**	0.9**
SR		-	0.5**	0.1	-0.1^{ns}	0.7**
PV			-	-0.1^{ns}	-0.3^{ns}	0.6**
APBP				-	0.8**	-0.3^{ns}
AS					-	-0.5**
NSPP						-

****Highly significant at 1 per cent level; superscript of ns= not significant at 1 per cent level, WS= Weight of Seed (g. plant^{-1}), SR=Survival Rate, PV= Plant Vigour, APBP= Aphid Population Build-Up, AS= Aphid Score, NSPP= No. of seeds per plant**

The moderate positive association of weight of seeds/plant with parameters such as plant vigour and survival rate are in agreement with the research by Makoi (2019). If the cowpea plants are disturbed in their growth and development process by either biotic or abiotic factors, this has the potential to reduce the yield of the crop. In the current study, the more affected cowpea genotypes by *A. craccivora* K had a lesser weight of seeds/plant compared to the cowpea genotypes that withstood the adverse effects of *A. craccivora* K. Thus, the relationship between the weight of seeds/plant and parameters such as plant vigour and survival rate were able to successfully reveal the genetic variations that exist between the susceptible cowpea genotypes e.g., BBBT1-5 and the resistant cowpea genotypes e.g., BBBT1-11. Though negative, the association between the weight of seeds/plant and aphid population build-up was non-significant. This is an indication that aphid population build-up (the number of aphid clusters/plant) does not have a significant bearing on the weight of the seeds/plant. However, the negative significant association between the weight of seeds/plant and the aphid score (number of aphids/plant) indicates that the number of aphids that attack a plant has a significant bearing on the weight of the seeds produced. Thus, the more the number of aphids on the cowpea plant, the lesser the weight of the seeds/plant produced. The moderate positive association between plant vigour and parameters such as survival rate and the number of seeds/plant confirms the findings of Singh et al (1996) and Giga (2001). The researchers reported that resistant varieties can grow vigorously with no or fewer damage symptoms and produce seeds compared to susceptible varieties, regardless of the insect pressure/infestation. Therefore, the positive association in the current study between plant vigour and survival rate and the number of seeds/plant can also be used to define the susceptible and the resistant cowpea genotypes. The more resistant cowpea genotypes exhibit good plant vigour that consequently resulted in a high survival rate and seed production compared to the susceptible genotypes. The highly significant positive association that existed between survival rate and the number of seeds/plant, is an indication that the more the cowpea genotype can survive/withstand the aphid pressure, the more likely it will produce a good amount of seeds/plant. This relationship further helps to define the susceptible and the resistant cowpea genotypes.

Conclusion

The most resistant genotype in the present study was BBBT1-11 based on all parameters investigated. BBBT1-11 could be assessed for the possible presence of biochemical traits that could explain the basis of the observed differences among the genotypes in their reaction to *Aphis craccivora* K. Besides, BBBT1-11 can also be incorporated in the breeding program with the target of breeding cowpea varieties that are tolerant to aphid infestation to address the yield losses experienced in cowpea production as a result of *A. craccivora* K.

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Conflict of Interest

The authors have not declared any conflict of interest.

Data Availability

Data is available upon request, by writing to the corresponding author.

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