Components and Mechanisms of Resistance in Selected Field Pea Lines to Pea Aphid (*Acyrthosiphon pisum* Harris) in Ethiopia

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Studies were conducted to assess the mechanisms of resistance in seven resistant field pea, *Pisum sativum* lines to *Acyrthosiphon pisum*, a serious pest of field pea in Ethiopia. The total number of nymphs produced per female was significantly lower ($P < 0.05$) on Holetta Local-90 (74.9), 061K-2 P-14/7/1 (76.9) and 305PS210687 (77.4) than on 304WA1101937 (95.4). There was no significant difference ($P > 0.05$) in the number of nymphs produced per female per day, number of days in nymphipositional period and longevity on all lines. The intrinsic rate of increase (r_m) on all lines was also not significant ($P > 0.05$). There were significant differences ($P < 0.05$) in preference of the aphid among the lines tested. Holetta Local-90 and 061K-2P-2/9/2 were less preferred than the others. The plant height and dry mass of 061K-2P-2/9/2 and 061K-2P-14/7/1 were significantly ($P < 0.05$) less affected than the other lines—showing that these lines are tolerant to *A. pisum*. Based on their response to *A. pisum* infestation, Holetta Local-90 and 305PS210687 lines performed better than the rest of the lines tested.

Key words: *Acyrthosiphon pisum*, fecundity, *Pisum sativum* resistance

Running title: Mechanisms of field pea resistance to pea aphid

Introduction

Field pea (*Pisum sativum* L.) is the third most important pulse crop in Ethiopia, next to faba bean and chickpea in terms of both area coverage and total annual production. It is a source of food, feed and cash to the producers and also plays a significant role in soil fertility restoration through biological nitrogen fixation. The pea aphid, *Acyrthosiphon pisum* (Harris) is an insect pest of considerable economic importance in the production of field pea and lentil in many areas of Ethiopia. However, infestations are usually high in mid-altitude areas (1800–2200 m).

Recommended methods for control of pea aphid include the application of insecticide and early planting (Ali & Habtewold 1994). Although insecticides are effective for the control of *A. pisum*, they are costly and have undesirable non-target effects. Moreover, in field pea growing regions of the country, most growers are subsistence farmers whose resources cannot warrant the use of synthetic insecticides against aphids. Russel & Morrison (1924) recognized host resistance as one of the most promising methods to control pea aphid in peas. Since this observation, numerous studies have been conducted to screen pea genotypes for resistance to pea

aphid (e.g. Markkula and Roukka 1971, Bieri *et al.* 1983, Downes 1994). Some resistant pea germplasm sources have been evaluated to determine the categories of resistance in operation (Dahms & Painter 1940, Campbell & Mackauer 1977, Soroka & Mackay 1991, Holtkamp & Clift 1993).

Result of a preliminary laboratory screening for resistance in 30 field pea genotypes against pea aphid had revealed six lines with various levels of resistance (Ali 2002). This study presents the results on components and mechanisms underlying resistance (antibiosis, tolerance and antixenosis effects) or susceptibility of these lines to *A. pisum*.

Materials and Methods

Lines and insect tested

Experiments on components and mechanisms underlying resistance of *A. pisum* lines Holetta Local-99 (08), 305PS210687 (13), 061K-2P-2/912 (14), 061K-2P-14/7/1 (18), JI-898 (22), 304WA1101937 (26), and NEP874UK (susceptible check) 15 to *A. P*isum were carried out at Holetta Agricultural Research Center insectary between July and September 2001. Colonies of *A. pisum* were established from field-collected apterous viviparous insects from pea plants in Holetta Agricultural Research Center farm. Insects were reared in insectary on seedlings of Mohanderfer pea (susceptible variety), at 22.7^0 C (day) and 15.5^0 C (night) and relative humidity of 70–94% from July to September 2001.

Antibiosis test: Three seeds per line were sown in perforated plastic pots (20 cm diameter) filled with sterilized soil (red soil) mixed with 250 mg Diamonium phosphate (18N, 45 P_2O_5 per kg of soil (Bekele pers. comm.). Six days latter, seedlings were thinned to 1 per pot. The pots were covered with clear cylindrical plastic cages (15 cm diameter and 60 cm high). The screen cages had holes covered with a fine mesh screen at the top and six sides for ventilation. Plants were watered when the soil was dry to the touch. Treatments (lines) were replicated 10 times and arranged in a randomized complete block design.

The aphids were allowed to larviposit for 24 hrs onto test plants. After the appearance of offspring, all aphids except one first instar nymph were removed. Singly caged, new born aphids produced in this way were referred to as standard aphid. The individually caged lines containing these nymphs were maintained in the insectary. The nymphs were kept on the test plant until they matured and began to reproduce. For the purpose of this study, all nymphs that were produced within 24 hrs period were assumed to be of a uniform age.

The developmental rate of each nymphal instar was determined by checking for ecdysis every 24 hrs from birth until adulthood. From these data, the mean duration of each nymphal instar was calculated. Aphid survivorship was recorded daily, and the nymphs produced were counted and removed carefully by fine camel brush. This was done every day until the female died. The prenymphipositional period of the adult was determined as the period between birth and the deposition of the first progeny. Plants were trimmed when they grew too large for the cages so as to facilitate the removal and replacement of cages each time the aphid counts were made. In all experiments, when the top 1–2 cm of the

soil in the pots became dry, water was added carefully to the soil so as not to wash the aphids off the plants.

Parameters measured for making inferences about antibiosis included fecundity (mean number of nymphs produced per female), nymphipositional period (mean number of days from production of the first progeny to the last progeny), mean maximum number of nymphs produced in a single day, mean number of nymphs produced per day and longevity (Soroka & Mackay 1991). The intrinsic rate of increase (r_m) for each line was estimated as $r_m = 0.74 (\log_e M_a/d)$ (Wyatt & White 1977), where 0.74 = constant, d = prenymphipositonal time and M_a = number of progeny produced in a time equal to prenymphipositonal time.

Values of the intrinsic rates of increase were computed daily and converted into finite rates of increases (number of individuals added to the population per female per day, or the population capacity to multiply a number of times per female per day). The finite rate of increase (λ) was given by the equation $\lambda = \text{antilog}_e r_m$ (De Loach 1974). Generation time (Td) was computed using Td = 4d/3, where d is the prenymphipositonal time. The time for the population size to double (DT) was estimated as $DT = [\log_e (2)]/r_m$.

Each of the measured parameters were statistically analyzed using one way ANOVA (MSTAT-C 1990) for making inferences about antibiosis. Means were compared using Least Significant Difference (LSD) at $P \leq 0.05$.

Antixenosis test: Schweissing & Wilde (1979) stated that antixenosis tests with apterous *Scizaphis graminum* (Rondani) (Homoptera: Aphididae) closely approximated the results obtained with alates. Apterous viviparous adult aphids were used in this free-choice experiment.

Single pea seedlings per pea line were randomly planted in equidistant holes around the edge of 26-cm diameter plastic pot (seven different lines per pot). The experiment was laid in a randomized complete block design (RCBD) with 10 replications. When plants were 15 days old, 70 *A. pisum* adults, i.e. 10 aphids per plant, were released in the center of each pot to allow each plant an equal opportunity of being infested. The pots were covered as described previously.

The number of aphid per plant was recorded after 24, 48, and 72 hours. First instar nymphs were excluded from the counts for host preference as they are less mobile and tend to feed on the nearest part of the plant, where they are deposited. The experiment was conducted after sunset (18:30 GMT) to avoid possible aphid phototaxis.

Where appropriate, data were $\sqrt{(x+0.5)}$ transformed and subjected to analysis of variance using (MSTAT-C) package. When F values were significant ($P < 0.05$), means were compared using LSD.

Tolerance Test: Seeds of each line were individually sown in a 15-cm diameter plastic pot. Two weeks after planting, two 9–10 cm tall seedlings per line were selected. One of them was caged with 10 adult apterous aphids, while the other one served as a control. The pots were then covered as in the antibiosis test.

Plants were examined every 48 hr and excess aphids were removed to maintain a

constant number of 10 aphids per cages on the infested plants. In the control, plants were removed from the cages every 48 h to mimic the manipulation of infested plants. Three weeks after infestation, plant height, fresh biomass, dry biomass, number of leaves and root biomass were recorded from both infested and non-infested plants. Fresh plants and roots were dried in an oven at 50^0 C for 72 hrs to get the dry mass. The percentage of each parameter was estimated as:

X = (1-[value of uninfected plant-value of infested/value of uninfested plant] x 100)

The experiment was designed as a one-factor RCB with five replications. Data were analyzed as described in the antixenosis test.

Resistance index study: The plant resistance index provides a single value to determine appropriate resistant lines for crosses (Inayatullah et al. 1990). As the antibiosis, tolerance, and antixenosis for the pea aphid populations were measured in different scales (nymphs/female, aphids/plant and plant damage), the data for each component was pulled to a common scale by dividing each value from a series of the test lines by the highest value occurring for that component. The resulting values were designated as mechanism indices.

A plant resistance index (PRI) per line was then calculated using the equation PRI = 1/(xyz), (Inayatullah *et al.* 1990);

Where x = the antibiosis index, y = the antixenosis, and z = tolerance indices.

Results

Antibiosis: The fecundity of the pea aphid on field pea lines 14 and 26 was significantly ($P < 0.05$) lower than on lines 08, 13 and 18—showing lower antibiosis of the former two lines (Table 1). However, the fecundity of the pea aphid on lines 15 an 22 was not significantly different from that on lines 14 and 26 ($P > 0.05$). The number of nymphs produced per adult (fecundity) ranged from an average of 95.4 ± 9.1 nymphs per adults fed on line 26 to 74.9 ± 9.0 nymphs from adults fed on line 08. The overall mean of nymphs per adult on all lines was 84.7 ± 7.5. There were no significant differences ($P > 0.05$) in the number of nymphs produced per female per day, number of days in nymphipositional period and longevity.

The r_m estimate of the intrinsic rate of population increase of *A. pisum* on all the lines was not significant ($P > 0.05$), indicating that separation of the lines based on this parameter is not possible for the lines have various combinations of antibiosis. The r_m value of the susceptible line was the lowest (0.284), although this value was not significantly different ($P > 0.05$) from that of the remaining lines. Mean generation and doubling times were similar among aphids reared on the seven lines (Table 2). The mean doubling time was also similar on all seven lines, with an overall average of less than 1 day.

Table 1. Mean ± SEM life table characteristics of pea aphid reared on seven pea lines in insectary

Entry Code #	Fecundity	Nymphs per female/ day	Nymphi-position period	Longevity	Maximum number of nymphs per ffemale/ 24 hr	Prenymphi-position period
Holetta Local-90	74.9±9.0d	5.2±1.1	15.0±3.1	30.9±2.6	10.9±1.9	10.6±0.7
305PS210687	77.4±14.9bcd	5.4±1.0	14.5±1.8	31.0±1.2	10.0±1.7	10.7±0.4
061K-2P-2/9/2	93.6±9.2a	5.5±0.7	16.7±1.9	32.0±3.0	11.6±2.3	10.5±0.9
061K-2P-14/7/1	86.7±11.7abcd	5.5±0.7	15.6±1.2	31.7±2.4	10.7±2.1	11.1±0.6
JI-898	76.6±12.0cd	5.1±0.8	15.9±1.8	32.4±2.0	10.4±1.5	10.9±0.8
304WA1101937	88.1±8.7abc	5.8±0.6	15.2±1.9	32.0±2.5	11.2±1.0	10.5±0.7
NEP874UK(susceptible check)	95.4±9.1a	6.2±0.7	15.6±2.1	30.7±2.0	11.4±1.0	10.1±0.3
Mean	84.7±7.5	5.5±0.3	15.5±0.6	31.5±2.1	10.9±0.5	10.6±0.3
CV (%)	13.6	15.0	14.3	8.2	16.4	6.5

Mean fecundity followed by different letters is significantly different (P< 0.05). ANOVA was followed by LSD test.

Table 2. Demographic statistics derived from the life table of individual pea aphids reared on pea lines

Entry ode #	r_m[a]	λ[b]	T[c]	DT[d]
Holetta Local-90	0.292	1.24	14.3	2.4
305PS210687	0.291	1.34	14.3	2.4
061K-2P-2/9/2	0.304	1.35	14.0	2.3
061K-2P-14/7/1	0.284	1.33	14.8	2.4
JI-898	0.293	1.32	14.5	2.5
304WA1101937	0.305	1.35	14.0	2.3
NEP874UK (susceptible check)	0.318	1.38	13.5	2.2
Mean	0.300	-	-	-
CV (%)	8.21	-	-	-

[a] Intrinsic rate of increase
[b] Rate of increase per female per day (finite rate of increase)
[c] Mean generation time, days
[d] Doubling time

Antixenosis: The antixenosis test indicated that pea aphids required only 24 hrs to select a preferred line (Table 3). There were significant differences ($P < 0.05$) among the seven lines for antixenosis. Not all the released *A. pisum* adults were recovered at the end of the test, but 601 (85.9 %) were recovered from 700 released individuals. Twenty four hours after release, line 26 had a significantly higher ($P < 0.05$) number of aphids (10.2 ± 1.9) compared to the remaining lines, except line 18. The number of adults recovered per plant 48 hrs after release was significantly different among the lines (P< 0.05, range 5.1± 1.0–8.4 ± 2.5). After 72 hrs, very few aphids had left the plants, resulting in a negligible decrease in the number of aphids per plant on all lines. Line 26 consistently sustained the highest number of aphids for settling and development. This shows the involvement of antixenosis (non-preference) as a mechanism of resistance to the pea aphid in this line.

Correlations between 24-hr and 48-hr ratings for antixenosis were significantly

different to correlation between 24-hr and 72-hr ratings ($r = 0.41$, $P < 0.01$; $r = 0.28$, $P < 0.05$), respectively. Correlation ratings between 48-hr and 72 hr were larger and highly significant ($r = 0.62$, $P < 0.001$).

Table 3. Mean number ± SEM of *Acyrthosiphon pisum* per plant 24, 48 and 72 hrs after infestation

Test line	Number of *A. pisum*		
	24 h	48 h	72h
Holetta Local-90	4.8 ± 1.5**c**	5.1 ± 1.0**b**	4.9 ± 1.8**cd**
305PS210687	7.4 ± 2.4**bc**	6.5 ± 2.2**ab**	6.2 ± 1.4**bcd**
061K-2P-2/9/2	6.2 ± 2.7**bc**	5.4 ± 2.2**b**	4.3 ± 1.3**d**
061K-2P-14/7/1	6.9 ± 2.0**b**	6.9 ± 1.8**ab**	7.5 ± 1.3**ab**
JI-898	8.3 ± 2.0**ab**	7.2 ± 1.5**ab**	7.3 ± 1.5**ab**
304WA1101937	7.7 ± 1.4**b**	6.5 ± 2.1**ab**	8.3 ± 2.2**a**
NEP874UK (susceptible check)	10.2 ± 1.9**a**	8.4 ± .5**a**	8.4 ± 2.1**a**
Mean	7.4 ± 0.75	6.6 ± 0.69	6.7 ± 0.63
CV (%)	30.33	31.25	28.39

Means followed by the same letter within a column are not significantly different (P>0.05); ANOVA followed by LSD test.

Tolerance: There was no significant variation ($P < 0.05$) in plant height at the beginning of the experiment and, therefore, the observed differences in plant height during the first 21 days was likely to have been caused by the effect that aphid feeding had on the field pea lines (Table 4). Significant differences ($P < 0.05$) were noted between uninfested tolerant test lines in plant growth, number of leaves, fresh and dry plant mass at the end of the test, indicating that the lines are different in their level of tolerance to the pea aphid. Stunting was very severe among the field pea lines, but the degree varied considerably among the lines. At the end of the experiment, all uninfested test lines attained average plant growth of 68.0 cm, whereas, the corresponding infested plants attained average plant growth of 21.4 cm. Growth of infested lines ranged from 16.1 cm in line 15 to 27.6 cm in line 14, with a test average of 21.4 cm (Table 4). The growth of uninfested line 15 was significantly lower ($P < 0.05$) than the growth of line 22.

The number of leaves produced by infested and uninfested field pea lines was significantly different ($P < 0.05$). The leaf number of infested lines ranged from 14.0 in line 13 to 30.6 in line 14, with an overall average of 22.7. The number of leaves was significantly ($P< 0.05$) lower in infested plants of lines 08 and 13, compared with lines 14, 18, 22 and 26. Fresh plant weight was significantly higher ($P< 0.05$) for line 14 than for all the entries except line 18 (Table 5). Mean fresh weight was 3.05 g for the control and 0.92 g for the infested plants. The fresh weight of infested lines ranged from 0.43 g in line 08 to 1.55 g in line 14, with a mean of 0.92 g. Line 14 showed a significantly more ($P< 0.05$) dry weight (58.8 %) than all the other lines, except lines 13 and 18 which showed dry weight of 35.6% and 38.6%, respectively.

Table 4. Growth of seven field pea lines subjected to pea aphid infestation

Test entry	Plant Height (cm)		Plant growth (cm)		% Uninfested plants
	To be infested	Not to be infested	Uninfested	Infested	
Holetta Local-90	15.2a	16.2a	70.0 ± 10.0ab	18.6 ± 4.1b	27.5b
305PS210687	12.9bc	13.7bc	68.0 ± 7.9ab	18.3 ± 1.9b	27.4b
061K-2P-2/9/2	15.0ab	13.5bc	68.2 ± 9.9ab	27.6 ± 3.7a	41.5a
061K-2P-14/7/1	10.9c	11.5c	63.0 ± 5.0b	16.1 ± 3.7 b	26.1b
JI-898	12.8c	12.2bc	70.8 ± 8.7ab	24.8 ± 5.4 a	35.9ab
304WA1101937	13.0bc	14.1ab	76.4 ± 9.0a	26.4 ± 7.6 a	34.6ab
NEP874UK(susceptible check)	11.9c	12.6bc	66.4 ± 6.7ab	18.2 ± 1.7 b	28.6b
Mean	13.1	13.4	68.0 ± 1.7	21.4 ± 3.4	31.7
CV (%)	12.6	13.9	14.3	21.7	28.2

Means followed by different letters within a column are significantly different (P< 0.05). ANOVA followed by LSD test.

Table 5. Tolerance indicators of seven field pea lines to pea aphid at Holetta

Entry Code #	No. leaf infested	% Uninfested	Fresh plant weight (g) infested	% Uninfested	Dry plant weight (g) infested	% Uninfested
08	14.4c	43.7bc	0.43de	25.6b	0.04c	27.8b
13	14.0c	39.2c	0.59de	29.0b	0.06c	35.6ab
14	30.6a	80.1a	1.55a	54.2a	0.16a	58.5a
15	21.4bc	59.8abc	0.59de	30.5b	0.06c	32.1b
18	25.0ab	69.5a	1.36ab	36.4ab	0.13ab	38.6ab
22	24.8ab	62.4ab	1.00bc	28.0b	0.11b	34.1b
26	28.8ab	60.7ab	0.94cd	25.4b	0.14ab	34.6b
Mean	22.7	59.4	0.92	32.7	0.10	37.3
CV (%)	25.6	27.2	31.7	45.5	33.8	43.7

Means followed by different letters within a column are significantly different (P < 0.05). ANOVA followed by LSD test.

Resistance index: Data based on tolerance components of normalized indices, indicate that lines 08, 13, and 15 were more resistant than the remaining lines. The most susceptible lines were 14, 18, 22 and 26 (Table 6) albeit that these lines were not as resistant in these tests as they were in the field. This lack of resistance may be the result of partly their low antibiosis.

Table 6.Normalized indices and overall resistance index (RI) based on components of resistance to *Acyrthosiphon pisum*

Entry Code #	Normalized indices			
	Antibiosis (x)	Antixenosis (y)	Tolerance (z)	PRI*
08	0.78	0.54	0.66	3.6
13	0.81	0.74	0.66	2.5
14	0.98	0.59	1.00	1.7
15	0.91	0.79	0.63	2.2
18	0.80	0.84	0.86	1.7
22	0.92	0.83	0.83	1.6
26	1.00	1.00	0.66	1.5

Discussion

Survival of *A. pisum* depends on the suitability of its host for feeding and reproduction. Soroka & Mackay (1991) examined six cultivars of peas with regard to their suitability for one strain of pea aphid. All measurements of pea aphid performance were affected by the pea variety. Similar results have been reported by Damte (1999) and Zeng et al. (1993) who studied differences in suitability for pea aphid survival and reproduction on lentil and red clover varieties. The results from the current study are similar to those presented by others.

The screening tests of mechanisms of resistance revealed only small differences in host suitability among the seven pea lines evaluated. Variation in aphid fecundity was the clearest expression of antibiosis resistance among the parameters tested. This is probably the single most important factor causing fluctuation in the intrinsic rate of increase. Based on this parameter (fecundity), lines 08, 13 and 18 were more resistant or less suitable for pea aphid survival than the remaining lines. The susceptible line was the most suitable host for the reproduction of pea aphid as demonstrated by the highest mean fecundity. The values obtained in this study are comparable to the mean values of nymphal production per aphid (range 77–97) reported by Girousse & Bournoville (1994) on two cultivars of alfalfa and Newman & Pimentel (1974) on peas (range 78–113).

Soroka & Mackay (1991) reported a pea aphid nymphal development time of 8.4 to 11.0 days and Sandström (1994) reported a pen aphid nymphal development time of 7.8 to 8.7 days, which are different from the values found for pea aphid on peas in this study. Furthermore, these authors reported a nymphipositional period of 11.3 to 13.8 days, which is shorter than the nymphipositional period found in the current study (14.5 to 16.7 days). These differences could be due to the different experimental conditions, pea aphid clones or differences on host types, or all three. Newman & Pimentel (1974) reported that adult pea aphid can survive for 27–34 days. However, Soroka & Mackay (1991) reported that the aphid lives for 20 – 26 days. Result of the current study indicated that pea aphid survives for 30-32 days.

The calculated natural intrinsic rate of increase (r_m) followed the rankings of the lines for each parameter. The r_m values presented in this study are within the range of r_m estimates presented for different pea cultivars under similar temperatures (Soroka & Mackay 1991, Morgan *et al.* 2001). However, Sandström (1994) reported higher estimates of 0.322 to 0.372, whereas, Hutchison & Hogg (1984) reported a r_m value as high as 0.380 on alfalfa. These differences could be due to the differences in host plants.

The antixenosis detected on field pea lines 08 and 14 also occur under field conditions and could influence the initial infestation level of pea aphids. However, the antixonesis detected for these lines is unlikely to make a significant contribution to the resistance of the lines under field conditions, since *A. pisum* can be reared successfully on these lines.

All lines were less tolerant to pea aphid feeding than the control as indicated by plant height and percentage of weight reduction. Based on plant height measurements, the selected lines were

moderately tolerant to pea aphid. All lines showed more or less similar stunting, except line 14 that was less severely stunted by pea aphid damage. Uninfested plants of most of the lines grew more than twice as tall as infested plants. Lines 14, 18 and 22 showed low to moderate levels of tolerance based on comparison to percentage of uninfested plant height after pea aphid feeding.

In this study, few field pea lines displayed the three categories of resistance. Soroka & Mackay (1991) showed both antibiosis and antixenosis in their findings, but tolerance was not found in any of the lines they evaluated. Holtkamp & Clift (1993) documented that antibiosis and antixenosis are the main mechanisms of resistance of some alfalfa cultivars to pea aphid. Maxwell et al. (1972) reported similar results, but also found that tolerance was also involved to some degree. Zeng *et al.* (1993) reported that one red clover line N-2 showed antibiosis resistance against pea aphid. However, no tolerance or antixenosis assessments were conducted on this line.

Tolerance as a mechanism of resistance may also provide resistance that is more stable than antibiosis or antixenosis (Smith 1989). Combining multiple categories of resistance in a single cultivar may prolong the resistance to *A. pisum* in adapted cultivars. The lack of high levels of reproductive antibiosis should negate or delay the development of *A. pisum* biotypes, and the tolerance response of these resistant sources should enable the aphids to survive on plants that support predator and parasitoid populations. Although these reductions may not be great, they may be important under light to moderate field infestation levels when they are combined with the effects of pea aphid biological control agents (van Emden 1990).

Host-plant resistance at the levels discussed in this study may become an important component of an IPM system because of its compatibility with the use of natural enemies (Dodd & van Emden 1979, van Emden 1990, Messina & Sorenson 2001). Methods based on partial host-plant resistance may help limit aphid populations to economically acceptable levels on pea crop, as well as imposing less selection pressure for the development of resistant aphid biotypes (Lammerink 1968, Dunn & Kempton 1972). Results suggest that antibiosis in field pea lines are affected by decreasing population rate. Further examination of the mechanisms of antibiosis (e.g., toxins, growth inhibitors, reduced nutrient levels, hypersensitive plant growth responses, or plant structure factors) is needed to assess the rate of antibiotic field pea resistance in *A. pisum* population development.

The results of the current work documented that line 08 has generally a high level of antibiosis and antixenosis but less tolerance, whereas, line 15 was susceptible to pea aphid in terms of the three mechanisms of resistance. Lines 08 and 13 may be useful sources of resistance to pea aphid when the three components are considered.

Acknowledgements

We thank Mr. Belay Eshetu, Mrs. Emebet Amogne and Ms. Lili Girma for their assistance in data collection and compilation. The study was supported by the Royal Dutch Government and the Ethiopian Agricultural Research organization.

References

Ali K. 2002. An integrated approach to pest management in field pea, *Pisum sativum* (L.) ,with emphasis on pea aphid, *Acyrthosiphon pisum* (Harris). PhD thesis, University of the Free State, Bloemfontein, South Africa. Pp. 313.

Ali K. and Habtewold T. 1994. Research on insect pests of cool-season food legumes. Pp 367–396. In: A. Telaye, Geletu Bejiga, M.C. Saxena & M.B. Solh (eds.). *Cool Season Food legumes of Ethiopia. Proceedings of 1st National Cool-Season Food Legumes Review Conference*. Addis Ababa, Ethiopia.

Bieri M. J Baumgartener, G Bianchi, R Delucchi, and V Von Arx. 1983. Development and fecundity of pea aphid (*Acyrthosiphon pisum* Harris) as affected by constant temperatures and pea varieties. Mitteilurgen der Schweizerischen Entomologischen Geselschaft. 56:163–171

Campbell A. and M Mackauer. 1977. Reproduction and population growth of the pea aphid (Homoptera: Aphididae) under laboratory and field conditions. Canadian Entomologist 109: 277–284.

Dahms, R G AND R H Painter, 1940. Rate of reproduction of the pea aphid on different alfalfa plants. *Journal of Economic Entomology* 33: 482–485.

Damte, T. 1999. Influence of different cultivars of lentil, *Lens culinaris*, on life history traits of pea aphid, *Acyrthosiphon pisum* (Homoptera: Aphididae). Unpublished MSc thesis, George August Universitaet, Goettingen, Germany.

De Loach C J. 1974. Rate of increase of populations of cabbage, green peach and turnip aphids at constant temperatures. Annals of Entomological Society of America 67: 332–361.

Dodd, G D and H F Van Emden. 1979. Shifts in host plant resistance to the cabbage aphid (*Brevicoryne brassicae*) exhibited by Brussels spouts. Annals of Applied Biology 91: 251–262.

Downes R W. 1994. New herbage cultivars, *Medicago sativa* L. (lucerne) cv. Alfanafa (syn. Sirosal). Tropical Grasslands 28(3): 191–192.

Duncan, D B. 1955. Multiple range and multiple F tests. Biometrics 11: 1–42.

Dunn, J A and D P H Kempton. 1972. Resistance to attack by *Brevicoryne brassicae* among plants of Brussels sprouts. Annals of Applied Biology 72: 1–12.

Girousse, C. and R Bournoville. 1994. Role of phloem sap quality and exudation characteristics on performance of pea aphid grown in lucerne genotypes. Entomologia Experimentalis et Applicata 70(3): 227–235.

Holtkamp, R H and A D Clift. 1993. Establishment of three species of lucerne aphids on 24 cultivars of lucerne. *Australian Journal of Agricultural Research* 44:53–58

Hutchison, W D and D B Hogg. 1984. Demographic statistics for the pea aphid (Homoptera: Aphididae) in Wisconsin and a comparison with other populations. Environmental Entomology 13:1173–1181.

Inayatullah C, J A Webster and W S Fargo. 1990. Index for measuring plant resistance to insects. Entomologist 109: 146–152.

Lammerink, S. 1968. A new biotype of cabbage aphid (*Brevicoryne brassicae* (L.)) on aphid resistant rape (*Brassica napus* L.). *New Zealand Journal of Agricultural Research* 11: 341–344.

Markkula M and K Roukka 1971. Resistance of plants to the pea aphid *Acyrthosiphon pisum* Harris (Homoptera: Aphididae). III. Fecundity on different pea varieties. Annales Agriculturae Fenniae 10: 33–37.

Maxwell F G, J N Jenkins and W L Parrott. 1972. Resistance of plants to insects. Advanced Agronomy 24: 187–265.

Messina F J, and S M Sorenson 2001. Effectiveness of lacewing larvae in reducing Russian wheat aphid populations on susceptible and resistant wheat. Biological control 21(1): 19–26.

Morgan D, K F A Walters and J N Aegerter. 2001. Effect of temperature and cultivar on pea aphid, *Acyrthosiphon pisum* (Hemiptera: Aphididae) life history. Bulletin of Entomological Research 91: 47–52.

Mstat-C. 1990. User's guide to MSTAT-C. A software program for the design, management and analysis of agronomic research experiments. Department of Crop and Soil Sciences, Michigan State University, East Lansing.

Newman W. and D Pimentel. 1974. Garden pea resistant to the pea aphid. *Journal of Economic Entomology* 67:365–367.

Russel G E and F B Morrison. 1924. New facts in farm science. Control of pea aphid. Wisconsin Agricultural Experiment Station Bulletin 362:61–64.

Sandström J. 1994. High variation in host adaptation among clones of the pea aphid, *Acyrthosiphon pisum* on peas, *Pisum sativum*. Entomologia Experimentalis et Applicata 71 (3): 245–256.

Schweissing F C and G Wilde. 1979. Predisposition and nonpreference of greenbug for certain host cultivars. Environmental Entomology 8: 1070–1072.

Smith C M 1989. *Plant resistance to insects: A fundamental approach*. John Wiley & Sons. New York. 286 pp.

Soroka J J and P A Mackay. 1991. Antibiosis and antixenosis to pea aphid (Homoptera: Aphididae) in cultivars of field peas. *Journal of Economic Entomology* 84:1951–1956.

Van Emden H F. 1990. The interaction of host plant resistance to insects with other control measures. *Proceedings of the 17th Brighton Crop Protection Conference, Pest and Diseases* 3: 939–948.

Wyatt I J and P R White. 1977. Simple estimation of intrinsic increase rates for aphids and tetranychid mites. *Journal of Applied Ecology* 14:757–766.

Zeng F, G A Pederson, F M Davis and M M Ellsbury. 1993. Modalities of resistance of N-2 red clover germplasm to pea aphid (Homoptera: Aphididae). *Journal of Agricultural Entomology* 11(4): 349–359.