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Development of Lentil (*Lens culinaris*) Genotypes Resistant to Pea Aphid, *Acyrthosiphon pisum* (Hemiptera: Aphididae) under Field Condition

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ABSTRACT

Development of effective and sustainable pea aphid (*Acyrthosiphon pisum*) management methods are required because it causes yield loss of 26% in lentil (*Lens culinaris*) through direct feeding and indirectly by transmitting several viral diseases. The aim of this study was to verify field resistance of lentil genotypes to pea aphid in locations that had different altitudinal ranges but similar cropping system. A pea aphid susceptible check variety EL-142 and eight resistant lentil genotypes were tested at four locations for four seasons in randomized complete block design with three replications. Seeds were sown in rows at the rate of 65 to 80 kg ha^{-1} and recommended planting date for each location. Pea aphid was sampled by beating the plants on a board that had six 10 cm × 13 cm (20 cm × 39 cm) rectangles. The seasonal pattern of pea aphid density build up was similar on both resistant and susceptible lentil genotypes. However, in seasons and locations where the pea aphid infestation was severe, the susceptible check had two to four times greater pea aphid density than the pea aphid resistant genotypes. Moreover, the percentage yield reduction was positive for all resistant genotypes and it ranged from 5.5 to 93.9%. The resistant lentil genotypes reduced the pea aphid density and gave higher (up to 1456 kg ha^{-1}) grain yield than the susceptible check (as low as 45 kg ha^{-1}). Thus, the resistant genotypes can be used independently or in combination with other pea aphid management tactics as required.

Key words: Aphid density, Cool season legumes, Field resistance, Grain yield, Insect resistance, Yield reduction.

The pea aphid, *Acyrthosiphon pisum* (Harris) (Hemiptera: Aphididae) infests lentil (*Lens culinaris* Medikus) and causes an average grain yield loss of 26% in Ethiopia (Tebkew and Mohammed, 2006) and 13% in Morocco (El Fakhouri *et al.,* 2021). Other than such direct damages by feeding, it vectors the luteoviruses (beet western yellow polerovirus (BWYV), soybean dwarf virus (SbDV)) and the pea seed-borne mosaic virus (PSbMV), which are currently major viral disease of lentil in Ethiopia (Berhanu *et al.,* 2005; Berhanu *et al*., 2021), India (Gautam *et al*., 2013) and other lentil producer countries (Flecher, 1993; Al-Mabrouk and Mansour, 1998; Coutts *et al.,* 2008).

To reduce these direct and indirect effects of pea aphid on Ethiopian lentil attempts have been made in the past several decades to devise effective, economical and environmentally friendly pea aphid management methods. Thus, information on the biology of pea aphid on lentil was generated (Melaku *et al*., 2000; Tebkew *et al.,* 2002) and the effects of sowing dates, plant density and insecticides on the incidence of this aphid species on lentil were assessed and recommendations drawn (Tebkew and Mohammed, 2006; Mintesinot, 2017). However, these nonchemical methods were not readily accepted by farmers and currently most of them rely solely on chemical insecticides to control pea aphid in lentil.

In addition to the nonchemical control methods, the searches for host plant resistance to pea aphid have been going on intermittently since the early 1990s during which close to 500 lentil genotypes were evaluated under field condition at Debre Zeit and Akaki, Ethiopia. Similarly, in India, the pea aphid is important pest of lentil but much work has not been done to screen genotypes for resistance (Singh, 1995). According to Edwards and Singh (2006) the success of host plant breeding for insect resistance depends on the access to the full range of germplasm; the possibility of achieving pest resistance without reducing agronomic qualities; and the existence of uniform insect infestations across locations and seasons. The use of insect-resistant varieties and cultivars, when available and practical, is the most economical, efficient, ecologically compatible and environmentally advantageous alternative to insecticides and is a key component in any integrated pest management (IPM) system due to its compatibility with other control measures (Sandhi and Reddy, 2020). However, according to Soundararajan *et al*. (2013) host plant resistance studies to insects have been limited only

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to pigeon pea, cowpea, chickpea and soybean, which suggests the need to study host plant resistance in lentil.

Under a laboratory, Alemtaye and van der Westhuizen (2004), in South Africa and a lathhouse Geteneh and Tebkew (2019), in Ethiopia, evaluated lentil for resistance to pea aphid and reported the presence of acceptable level of antibiosis, antixenosis and tolerance types of resistances. Similarly, Das *et al.* (2022), in the USA, screened several lentil germplasms that were collected from different lentil growing regions of the world under controlled environment and found antibiosis and antixenosis types of resistance to pea aphid. In all these screening works the pea aphid population used was established from a single parent that ignores clonal variation in pea aphid. However, Zafeiriou *et al.* (2022) raised pea aphid from several parents and using this pea aphid population they found antixenosis and tolerance type of resistance from lentil germplasms that were collected in Greece. However, the pea aphid resistances that were identified under controlled conditions were not confirmed in field condition. Geteneh and Tebkew (2019) verified lentil genotypes selected as resistant under lathhouse condition in field for one year and they found that the most resistant genotype under lathhouse condition was moderately resistant in field condition.

Although the results from such laboratory and lathhouse screening works were promising in finding resistant lentil genotypes to pea aphid, so far pea aphid resistant improved cultivars have not been released for use in any of these countries. According to Sharma and Ortiz (2002) the resistant genotypes that were identified under controlled environment might not be resistant to the heterogeneous pest population in the field and might not be readily accepted by farmers. Thus, the objective of this study was to verify field resistance of lentil genotypes to pea aphid under different locations and seasons.

Study locations and crop establishment

The pea aphid susceptible variety EL-142 was compared in four seasons with eight pea aphid resistant lentil genotypes between 2018 and 2021 cropping seasons at Debre Zeit (Altitude 1900 m a.s.l., 8°44′N and 38°58′E), Minjar (Altitude 1800 m a.s.l., 8°54′N and 39°24′E), Chefe Donsa (Altitude 2400 m a.s.l., 8°57′N and 39°6′E) and Akaki (Altitude 2200 m a.s.l., 8°53′N and 38°49′E). The EL-142 variety of lentil was released in 1980 through selection from Ethiopian lentil germplasm; whereas the resistant genotypes were introduced from the International Center for Agricultural Research in the Dry Areas (ICARDA) and tested at Debre Zeit for two successive seasons under field condition. Alemaya-ch/11-4, ILL-7664-ch/11-1, ILL-7664-ch/11-2 and ILL-7664-ch/11-3 are single plant selection, whereas the remaining genotypes are population. At each location and in each season, each genotype was sown in plot of 2 × 4 m^2. The planting dates at Debre Zeit were 31 July 2018, 31 July 2019, 29 July 2020 and 10 August 2021. Similarly, the planting dates at Minjar were 20 July 2018, 23 July 2019, 27 July 2020 and 23 July 2021. The corresponding planting dates at Akaki were 16 August, 2 August, 18 August and 17 August. At Chefe Donsa, the planting dates were 10, 9, 20, 14 August in 2018, 2019, 2020 and 2021 cropping seasons, respectively.

Pea aphid sampling

Pea aphid sampling dates were variable within and among locations due to the difference in first appearance of pea aphid in each location and season. Pea aphid was sampled by beating the plants on 39 × 20 cm^2 counting board that was divided in to six 10 × 13 cm^2 rectangles. Then, the pea aphids were counted from two randomly chosen 10 × 13 cm^2 rectangles. For each genotype pea aphid samples were taken at four spots per plot, which makes the total number of counts eight per plot. From these eight counts average density per 130 cm^2 was calculated. Moreover, grain yield was taken by harvesting the entire plot.

Data analysis

The genotypes were tested in randomized complete block (RCB) design with three replications. Thus, to determine the effect of genotypes on pea aphid density and grain yield, the pea aphid count from each sampling date in a location and the grain yield data were analyzed separately through using RCB design. However, to determine if sampling date and sampling date by genotype interaction had effect on pea aphid density, the pea aphid count data were analyzed as three factor (genotype, sampling date and block) factorial arrangement in RCB design. Both analyses were performed by Proc ANOVA of SAS and means were separated using Tukey at either p = 0.05 or p = 0.01 depending upon the level of significance. Before analysis, all the count data were transformed either to log x or log x + 1 (where x = the original data) depending upon the presence of zero value or not. However, only means of original count data were reported. Yield reduction due to pea aphid infestation was calculated by modifying the formula described by Smith *et al.* (1994).

$$\text{Yield reduction} = \frac{\text{Yield of resistant genotype} - \text{Yield of susceptible genotype}}{\text{Yield of resistant genotype}} \times 100$$

Debre zeit

In 2018 and 2019 cropping seasons, only sampling date did significantly ($p<0.05$) affect pea aphid density. Thus, between the second week and end of the fourth week of September 2018, the pea aphid density continuously increased, but it dramatically decreased on all genotypes in the first week of October 2018 (Fig 1A and B). On the other hand, there were no statistically significant ($p>0.05$) differences among genotypes and genotype by sampling date interaction in pea aphid density. The susceptible check (EL-142) had the highest (10.8/ 130 cm^2) pea aphid density. Whereas the genotype ILL-7664-ch/11-3 had the lowest (6.7/ 130 cm^2) pea aphid density. In 2019 cropping season, with the exception of 23 September 2019 sampling, the pea aphid density was on the average about two per

130 cm² (Fig 1B). On the 23 September 2019 sampling, when the genotypes were at six to eight leaf stage, the pea aphid density per 130 cm² varied between 6.0 on ILL-10021 and 10.0 on ILL-7664-ch/11-2.

In 2020 crop season, there was statistically significant difference ($p<0.05$) among genotypes and sampling date in pea aphid density on 14 September and 21 September 2020 sampling dates. However, there was no statistically significant ($p>0.05$) difference among genotypes and genotype by sampling date interaction in the remaining sampling dates. The pattern of pea aphid density fluctuation in 2020 crop season was similar to the density fluctuation in 2018 crop season (Fig 1C). Besides, although the pattern of pea aphid density increase was similar on all genotypes, on both 14 and 21 September 2020 sampling dates, the check cultivar had significantly greater pea aphid density per 130 cm² than all the resistant genotypes. On 14 September 2020, the genotypes ILL-2595, ILL-4422 and ILL-10021 were at full flowering stage; ILL-4416 was at the beginning of flowering (one flower per plot) and the rest genotypes were at 10 to 15 leaf stage.

Similarly, in the 2021 cropping season, there was significant ($p<0.05$) difference among lentil genotypes and sampling dates in pea aphid density. On the 16, 24 and 30 September 2021 sampling dates, the highest pea aphid density, which ranged from 6.8 to 12.0 pea aphids per 130 cm², was found on the susceptible check cultivar (Fig 1D). On the contrary, within same time span the genotypes ILL-2595 and ILL-4416 had the lowest pea aphid density, which was at most 3 pea aphids per 130 cm². On 16 September 2021, the genotypes ILL-2595, ILL-4422 and ILL-10021 had begun flowering, whereas the rest genotypes were at vegetative stage (8 to 11 leaf stage). By 11 November 2021, all genotypes had matured and were ready for harvest. As depicted on Fig 1D, except on the check cultivar and ILL-7664-ch/11-1, the pea aphid density increased during the second and third weeks of September 2021. However, beginning from the fourth week of September 2021 pea aphid density continuously decreased up to the fourth week of October 2021 on all genotypes. Between the last week of October 2021 and the third week of November 2021 the pea aphid density increased again and on 11 November 2021 sampling, the genotypes Alemaya-ch/11-4, ILL-7664-ch/11-1, ILL-7664-ch/11-2, ILL-7664-ch/11-3 and ILL-10021 had a greater number of pea aphid per 130 cm² than the rest genotypes.

The mean grain yield of pea aphid resistant lentil genotypes grown at *Debre Zeit* between 2018 and 2021 cropping seasons are given in Table 1. In the first two seasons, there was no statistically significant ($p>0.05$) difference among lentil genotypes in grain yield; whereas in the subsequent two seasons the susceptible check EL-

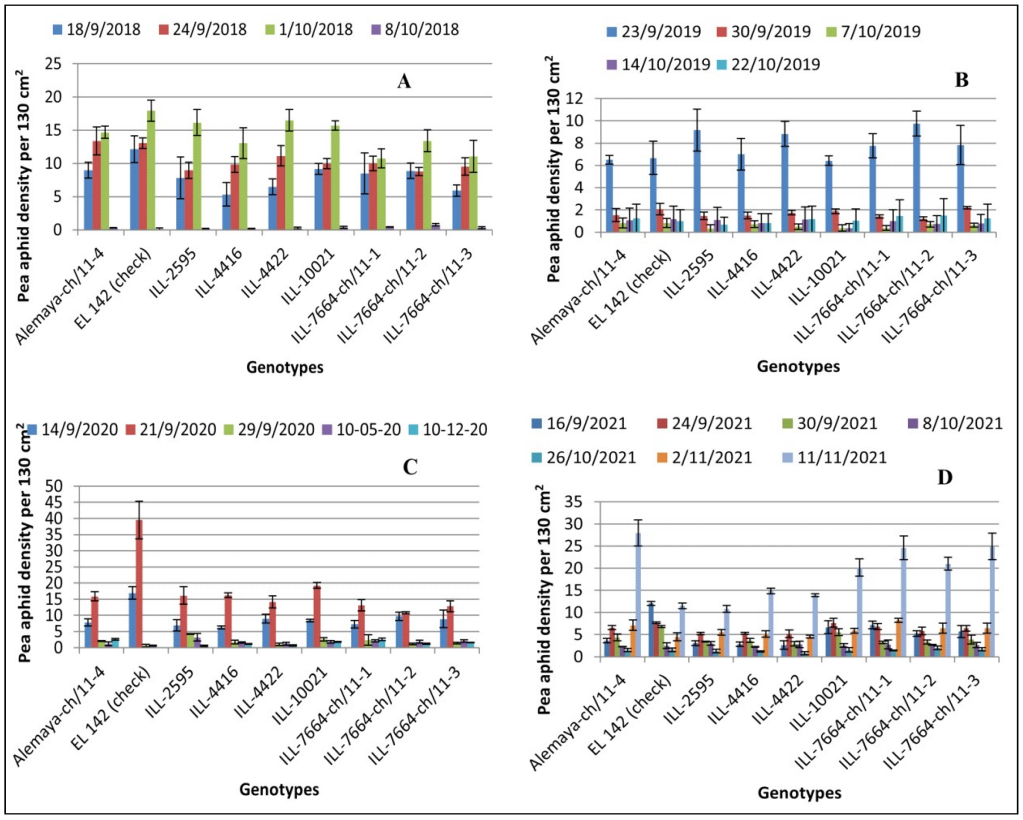


Fig 1: Pea aphid occurrences (bars indicate standard error of mean) on pea aphid resistant and susceptible lentil genotypes at Debre Zeit in 2018 (A), 2019 (B), 2020 (C) and 2021 (D) cropping seasons.

Table 1: Grain yield of pea aphid resistant lentil genotypes grown at Debre Zeit between 2018 and 2021 cropping seasons.

Genotypes	Grain yield (kg/ha) in a cropping season							
	2018 ($\bar{X}\pm SE$)	Yield reduction (%)	2019 ($\bar{X}\pm SE$)	Yield reduction (%)	2020 ($\bar{X}\pm SE$)	Yield reduction (%)	2021 ($\bar{X}\pm SE$)	Yield reduction (%)
Alemaya-ch/11-4	515.00±252.12	-94.34	640.83±112.51	51.95	390.83^{ab}±55.37	73.67	608.75^{cd} ±81.73	96.24
ILL-2595	936.25±12.33	-6.89	370.00±6.96	16.78	314.17^{a-c} ±67.72	67.24	1186.67^{a} ±126.85	98.07
ILL-4416	540.42±48.38	-85.19	711.25±145.32	56.7	203.75^{bc} ±31.69	49.49	816.67^{bc} ±103.08	97.19
ILL-4422	447.08±80.97	-123.86	577.92±39.43	46.72	178.75^{bc} ±29.47	42.43	871.67^{b} ±36.86	97.37
ILL-10021	350.42±69.43	-185.61	699.17±69.11	55.96	235.42^{a-c} ±49.08	56.28	750.83^{bc} ±66.22	96.95
ILL-7664-ch/11-1	192.92±30.49	-418.78	582.92±162.96	47.18	313.75^{a-c} ±19.86	67.19	575.42^{cd} ±44.02	96.02
ILL-7664-ch/11-2	630.41±59.03	-58.716	533.75±39.02	42.31	186.25^{bc} ±10.03	44.74	487.08^{d} ±57.31	95.3
ILL-7664-ch/11-3	791.67±125.94	-26.42	475.00±21.52	35.18	443.33^{a} ±50.73	76.79	834.58^{bc} ±123.58	97.25
EL 142 (check)	1000.83±75.22	-	307.92±39.64	-	102.92^{c} ±58.07	-	22.92^{e} ±5.22	-
CV(%)	31.9	-	26.5	-	31.2	-	13.2	-

*= means followed by the same letter within a column are not statistically different at p = 0.05.

142 had significantly ($p<0.05$) less grain yield than the resistant genotypes. In the 2018 cropping season, the check cultivar out yielded all the resistant genotypes as a result of which the percentage yield reductions were negative for all resistant genotypes. However, during the subsequent three cropping seasons, the susceptible check yielded less grain yield than the resistant genotypes. Consequently, the percentage yield reductions were positive for all resistant genotypes and it ranged from 17 to 57% in 2019 cropping season; 42 to 77% in 2020 and 95 to 98% in 2021. In both 2020 and 2021 cropping seasons, other than the severe pea aphid infestations, the susceptible check-EL-142-was also severely affected by viral diseases.

Minjar

In 2018 cropping season, pea aphid count was taken only one time. At this sampling date, there was highly significant ($p<0.01$) difference among genotypes in pea aphid density. Thus, the susceptible check EL-142 had the highest (26.2/ 130 cm^2) pea aphid density, which was followed by ILL-10021 (22.3), ILL-4422 (20.4), ILL-7664-ch/11-1 (17.6) and Alemaya-ch/11-4 (17.0). On the other hand, the, lowest pea aphid density (8.9/ 130 cm^2) was recorded on the genotype ILL-7664-ch/11-2. The crop was at maturity stage when the datum was recorded.

In 2019 cropping season, the effect of sampling date on pea aphid density was statistically ($p<0.05$) significant. However, there was no statistically significant ($p>0.05$) difference among genotypes and genotype by sampling date interaction. Thus, in the second and third week of September 2019 the pea aphid density increased on all genotypes and peaked on 17 September 2019 (Fig 2A). However, in the fourth week of September 2019 and thereafter, the pea aphid density crashed on all genotypes and reached less than one pea aphid per 130 cm^2. The pea aphid started infestation of lentil at the beginning of flowering. The pea aphid density, particularly on 17 September 2019, was very high on all genotypes and this high aphid infestation was coupled with severe damage by Ascochyta blight (*Ascochyta lentis* Bond. and Vassil). Consequently, the susceptible check EL-142, ILL-4422 and ILL-4416 died before attaining maturity. On the 17 September 2019 sampling, as many as 55.6 pea aphids per 130 cm^2 was found on cultivar ILL-2595. Whereas the genotypes ILL-4664-ch/11-2 and ILL-4664-ch/11-3 had the lowest pea aphid density (Fig 2A).

Similarly, in 2020 cropping season, sampling date had highly significant ($p<0.01$) effect on pea aphid density. Whereas, there were no statistically significant differences ($p>0.05$) among the genotypes and genotypes by sampling date interaction in pea aphid density. The pea aphid appeared when the test genotypes were at reproductive stage and it increased slowly on all genotypes between the third week of September and end of second week of October (Fig 2B).

However, in 2021 cropping season, there was significant ($p<0.05$) difference among lentil genotypes and sampling dates in pea aphid density. Whereas, the interaction effect between genotype and sampling date did not significantly affect the pea aphid density. It was found that the susceptible check had the highest pea aphid density throughout the cropping season (Fig 2C). Thus, when the pea aphid density peaks there were 53.94 pea aphids per 130 cm^2 on the check (EL-142), followed by ILL-4422, Alemaya-ch/11-4, ILL-2595 and ILL-7664-ch/11-1, which had 33.13 to 43.94% less pea aphid per 130 cm^2 than EL-142. On the other hand, ILL-4416, ILL-10021 and ILL-7664-ch/11-3 had the lowest (25.13/130 cm^2) pea aphid densities. However, pea aphid density growth pattern was similar on all genotypes and increased continuously between the end of the first week of September and third week of September 2021, but it declined in the fourth week of September and thereafter. In the first week of September the genotypes ILL-2595, ILL-4422 and ILL-10021 had begun flowering, whereas the other genotypes were at vegetative growth. However, by the third week of September all genotypes were at flowering stage.

The differences in grain yield among the lentil genotypes were statistically significant ($p<0.05$) in all cropping seasons (Table 2). In 2018 cropping season, as was the case at *Debre Zeit*, the check cultivar out yielded all the resistant lentil genotypes as a result of which there was negative yield reductions on all resistant genotypes. On the other hand, in the subsequent two cropping seasons, the check cultivar gave significantly lower grain yield than the resistant genotypes. Thus, in 2019 and 2020 cropping seasons all the resistant genotypes out yielded over the check cultivar by 31 to 87% and 52 to 87%, respectively. Among the resistant genotypes Alemaya-ch/11-4, ILL-7664-ch/11-1, ILL-7664-ch/11-3 and ILL-7664-ch/11-2 gave the highest grain yield in both seasons. The pattern of yield difference between the pea aphid resistant lentil genotypes and the susceptible check in 2021 was similar to the preceding two cropping seasons. However, the only exception was ILL-4416, which had grain yield less than the susceptible check-EL-142.

Chefe donsa

In 2018 cropping season, except on 12 October 2018 sampling date, there were no statistically significant ($p>0.05$) differences among genotypes. Moreover, genotype by sampling date interaction had no effect on pea aphid density. On the other hand, on 12 October 2018 sampling, there were statistically significant ($p<0.05$) difference among genotypes in pea aphid density. Thus, the highest

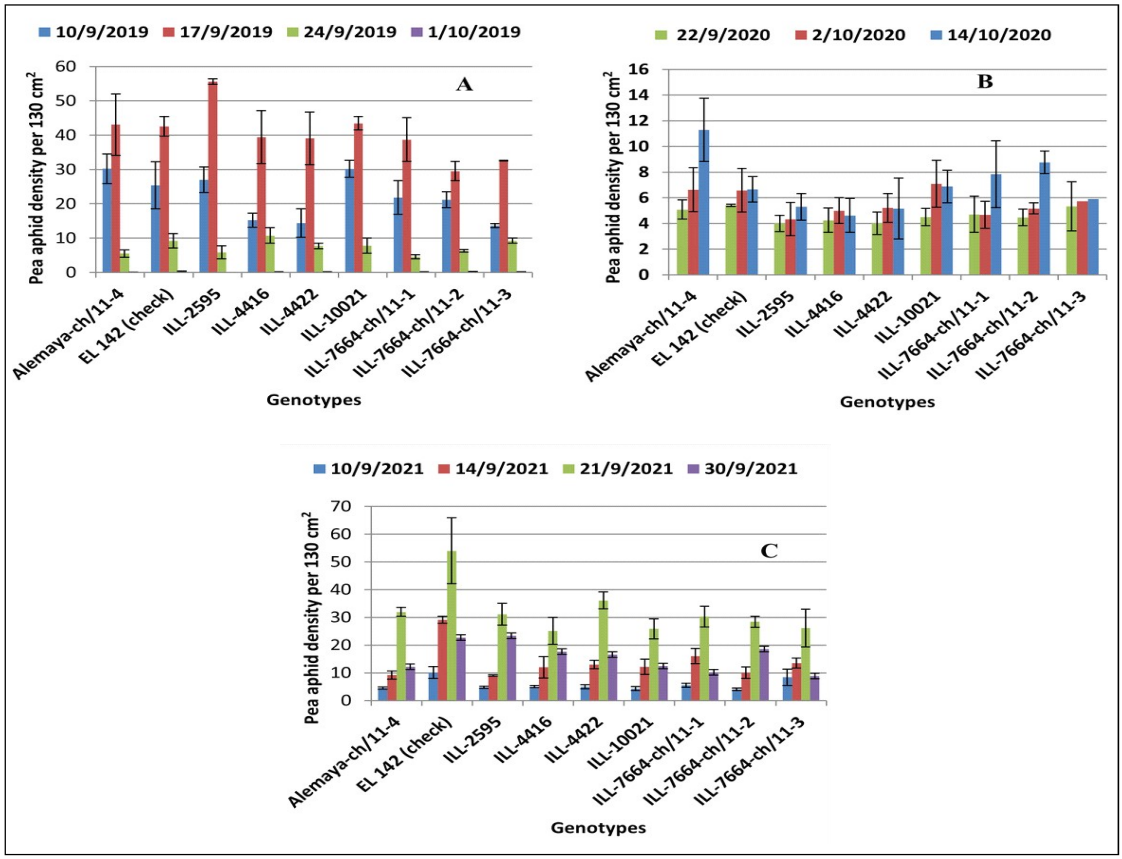


Fig 2: Occurrence of pea aphid (bars indicate standard error of mean) on pea aphid resistant and susceptible lentil genotypes grown at Minjar site in 2019 (A), 2020 (B) and 2021 (C) cropping seasons.

Table 2: Grain yield of pea aphid resistant lentil genotypes grown at Minjar site between 2018 and 2021 cropping seasons.

Genotype	Grain yield (kg/ha) in a cropping seasons							
	2018 ($\overline{X}\pm SE$)	Yield reduction (%)	2019 ($\overline{X}\pm SE$)	Yield reduction (%)	2020 ($\overline{X}\pm SE$)	Yield reduction (%)	2021 ($\overline{X}\pm SE$)	Yield reduction (%)
Alemaya-ch/11-4	727.50^{a-c}± 305.74	-96.22	373.33^{a}±46.86	87.05	430.00^{ab}±66.06	85.56	397.08^{a}±47.17	65.69
ILL-2595	526.67^{bc}±31.03	-171.04	127.08^{a-c}±13.09	61.97	135.00^{bc}±56.35	54.01	185.83^{bc}±18.27	26.68
ILL-4416	610.17^{bc}±49.77	-133.95	97.92^{bc}±18.96	50.64	130.42^{bc}±17.39	52.4	35.42^{c}±7.37	-284.71
ILL-4422	228.33^{c}±24.59	-525.18	70.00^{bc}±8.32	30.95	163.33^{bc}±63.17	61.99	136.25^{c}±33.07	0
ILL-10021	504.17^{bc}±130.24	-183.14	215.00^{a-c}±74.19	77.52	222.08^{a-c}±64.04	72.05	183.75^{bc}±31.22	25.85
ILL-7664-ch/11-1	1069.17^{ab}±40.58	-33.52	328.33^{a-c}±57.84	85.28	397.08^{ab}±73.46	84.37	386.67^{a}±35.14	64.76
ILL-7664-ch/11-2	938.33^{a-c}±85.47	-52.13	263.33^{a-c}±100.61	81.65	268.33^{a-c}±14.19	76.86	304.17^{ab}±38.66	55.21
ILL-7664-ch/11-3	1194.16^{ab}±43.21	-19.54	280.42^{a-c}±50.04	82.76	465.83^{a}±107.26	86.67	375.42^{a}±20.63	63.71
EL 142 (check)	1427.50^{a}±83.90	-	48.33^{c}±15.14	-	62.08^{c}±16.62	-	136.25^{c}±52.38	-
CV (%)	25	-	45		41.2		22.7	

* means followed by the same letters within a column are not statistically different at p = 0.05.

pea aphid density was found in the check (EL-142) followed by ILL-10021 and Alemaya-ch/11-4 (Fig 3A). At peak pea aphid densities, there were 14.29 pea aphids per 130 cm^2 on EL-142, 8.29 on ILL-10021 and 6.63 on Alemaya-ch/11-4. On the other hand, the other genotypes had relatively low pea aphid density throughout the growing season. The pea aphid density increased between the second and third week of October; however, it decreased significantly in the fourth week of October.

In 2019 cropping season, the pea aphid density was at most one pea aphid per 130 cm^2 throughout the cropping season. During 2020 cropping season, the pea aphid appeared at the seven to nine leaf stage and on 4 November 2020 sampling date. At this date, there was significantly ($p<0.05$) higher number of pea aphids per 130 cm^2 on Alemaya-ch/11-4 than the other genotypes, which was followed, in decreasing order, by the susceptible check (EL-142), ILL-7664-ch/11-3 and ILL-7664-ch/11-1 (Fig 3B). But the large standard error (2.98) of mean of pea aphid density on Alemaya-ch/11-4 suggests that the infestation was not uniform within replications. Sampling date also highly significantly ($p<0.01$) affected pea aphid density. Thus, except on ILL-4422 on which the pea aphid density did not increase in the season, the pea aphid density increased in the rest genotypes between the second week of October and first week of November 2020 (Fig 3B). The pea aphid density declined in second week of November and thereafter.

In 2021 season genotypes, sampling date and genotype by sampling date interaction had no significant ($p>0.05$) effect on pea aphid density. When the pea aphid density peaked, there was at most 6.67/ 130 cm^2 pea aphids on Alemaya-ch/11-4 and 6.42/ 130 cm^2 on ILL-7664-ch/11-3 (Fig 3C).

At *Chefe Donsa*, lentil genotypes did differ significantly ($p<0.05$) in grain yield in 2020 cropping season (Table 3) but not in 2018 and 2021 cropping seasons. In 2018 cropping season, the genotypes Alemaya-ch/11-4, ILL-2595 and ILL-4422 yielded less than the check due to waterlogging problem. Consequently, the percentage yield reduction was negative for these genotypes. On the other hand, the remaining pea aphid resistant lentil genotypes gave greater grain yield than the susceptible check EL-142 and thus the yield reduction was positive and ranged from 6 to 31%.

During 2020 and 2021 cropping seasons, pea aphid resistant lentil genotypes gave significantly ($p<0.05$) greater grain yield than the susceptible check El-142 (Table 3). In 2020 cropping season, the highest (673.75 kg ha^{-1}) and the lowest (112.08 kg ha^{-1}) grain yield were obtained from the genotype ILL-2595 and the susceptible check EL-142, respectively. The percentage yield reduction ranged from 21 to 83%. Similarly, in 2021 cropping season, all the pea aphid resistant lentil genotypes gave greater grain yield than the susceptible check EL-142.

Akaki

In 2018 cropping season, the pea aphid density at Akaki was at most one pea aphid per 130 cm^2 throughout the

season. But in 2019 cropping season, the seeds did not germinate due to abrupt termination of rainfall. In the succeeding 2020 and 2021 cropping seasons, the effects of lentil genotypes, sampling date and genotype by sampling date interaction on pea aphid density were statistically non-significant (p>0.05). In 2020 cropping season, the pea aphid infestation began when the genotypes were at six to eight leaf stage but the pea aphid density was at most 3 per 130 cm^2 throughout the growing season (Fig 4A). Similarly, in 2021 cropping season, pea aphid began to infest at early vegetative stage and remained at low density up to the end of third week of October. At peak pea aphid density in the last week of October (Fig 4B), there were 9.75 pea aphids per 130 cm^2 on ILL-7664-ch/11-1, 9.50 on ILL-7664-ch/11-3 and 9.17 on ILL-4416. However, in the first week of November, pea aphid density began to decline continuously on all genotypes and there were less than one pea aphid per 130 cm^2 in the last week of November.

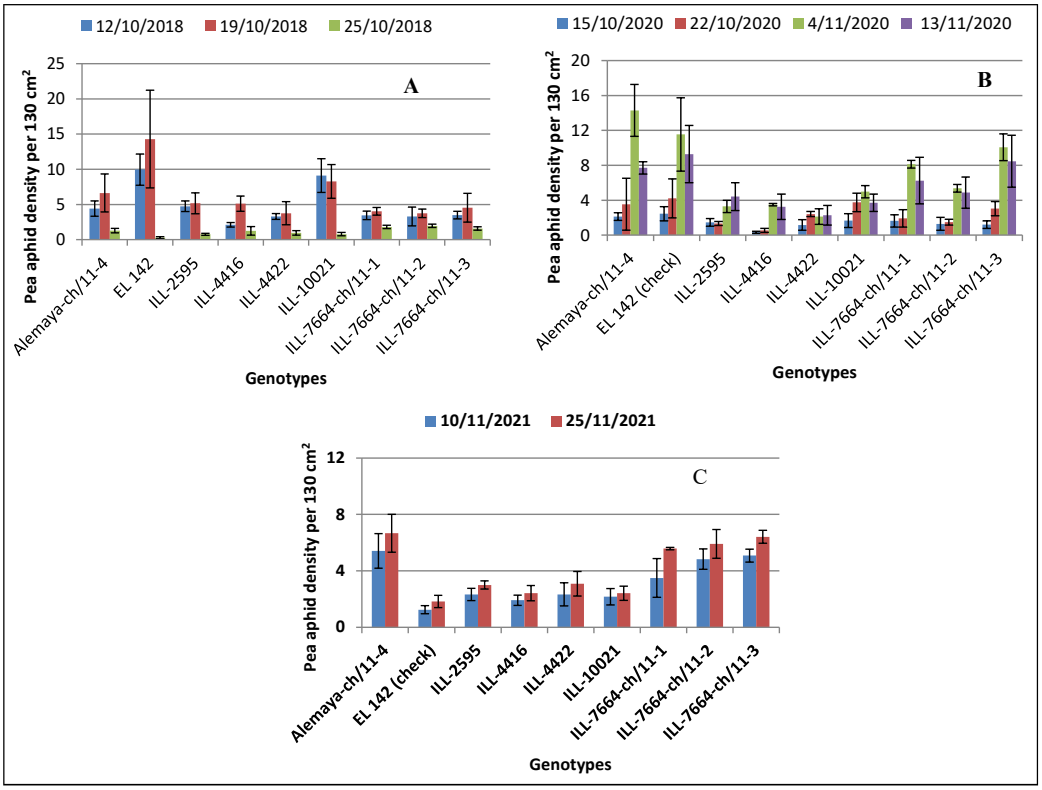


Fig 3: Occurrence of pea aphid (bars indicate standard error of mean) on pea aphid resistant and susceptible lentil genotypes at Chefe Donsa in 2018 (A), in 2020 (B) and in 2021 (C) cropping seasons.

Table 3: Grain yield of pea aphid resistant lentil genotypes grown at Chefe Donsa site in 2018, 2020 and 2021 cropping seasons.

Genotypes	Grain yield (kg/ha) in a cropping season					
	2018 (X±*SE)*	Yield reduction (%)	2020 (X±*SE)*	Yield reduction (%)	2021 (X±*SE)*	Yield reduction (%)
Alemaya-ch/11-4	784.17 ± 27.02	-28.37	265.00^{cd} ± 32.63	57.70	1176.99 ± 139.32	69.34
ILL-2595	859.58 ± 106.92	-17.11	673.75^{a} ± 50.25	83.36	1122.50 ± 182.73	67.85
ILL-4416	1065.42 ± 98.59	5.51	193.33^{cd} ± 20.88	42.03	857.92 ± 372.34	57.94
ILL-4422	912.08 ± 85.19	-10.37	328.75^{b-d} ± 52.02	65.91	660.83 ± 122.95	45.39
ILL-10021	1092.50 ± 130.64	7.86	482.50^{ab} ± 60.42	76.77	1073.75 ± 126.49	66.39
ILL-7664-ch/11-1	1382.50 ± 79.22	27.18	268.33^{b-d} ± 70.38	58.23	737.08 ± 80.64	51.04
ILL-7664-ch/11-2	1456.90 ± 125.45	30.9	142.50^{d} ± 11.27	21.35	605.96 ± 90.33	40.45
ILL-7664-ch/11-3	1082.92 ± 304.56	7.04	370.42^{bc} ± 44.35	69.74	1094.17 ± 206.29	67.02
EL 142 (check)	1006.67 ± 169.68	-	112.08^{d} ± 17.33	-	360.83 ± 52.92	
CV (%)	24.2	-	23.7	-	37.9	

*means followed by the same letters within a column are not statistically different at p=0.05.

In 2018 and 2019 cropping seasons, yield data were not obtained. In both 2020 and 2021 cropping seasons, the resistant lentil genotypes had significantly ($p<0.05$) greater grain yield than the susceptible check EL-142 (Table 4). Thus, in both seasons, genotypes ILL-2595, Alemaya-ch/11-4, ILL-10021 and ILL-7664-ch/11-3 gave higher grain yield than the other genotypes. Moreover, the percentage yield reduction ranged from 47 to 82% and 88 to 94% in 2020 and 2021 cropping seasons, respectively.

The genotype by sampling date interaction did not affect pea aphid density in all years and all locations, which suggests that the pattern of pea aphid population buildup on all the tested genotypes was similar (Fig 1-4). Moreover, in years and locations where the pea aphid densities were very high (Fig 1A and 1B at *Debre Zeit*; Fig 2A and 2C at *Minjar*), the densities of pea aphids per 130 cm^2 on the susceptible check was always greater than the pea aphid densities on the resistant lentil genotypes throughout the growing season. According to Hill *et al.* (2004) in resistant soybean *(Glycine max* L.) genotypes to the soybean aphid (*Aphis glycines* Matsumura) resistance is expressed in all plant stages. Thus, by the same analogy, the low pea aphid density on the resistant lentil genotypes in any growing season suggests that resistance to pea aphid might have been expressed throughout the developmental stages of the lentil plants. The other reason for the low pea aphid density on the pea aphid resistant genotypes might be due to the reduced rate of reproduction and total number of progenies born from pea aphids that fed on the resistant genotypes. For instance, the pea aphids reared on resistant lentil (Alemtaye and van der Westhuizen, 2004) and field pea (*Pisum sativum* L.) (Soroka and Mackay, 1991) have less number of progenies than those reared on susceptible genotypes. Similarly, in a field study, Du Toit (1990) found that the Russian wheat aphid (*Diuraphis noxia* (Mordvilko)) has less number of progenies on resistant bread wheat (*Triticum aestivum* L.) lines than on susceptible ones.

In this study, the pea aphid infested all lentil genotypes at all locations and seasons regardless of the difference in maturity period and pea aphid resistance level, which suggests the absence of scape (pseudo) type of resistance in the resistant genotypes. It also suggests that pea aphid

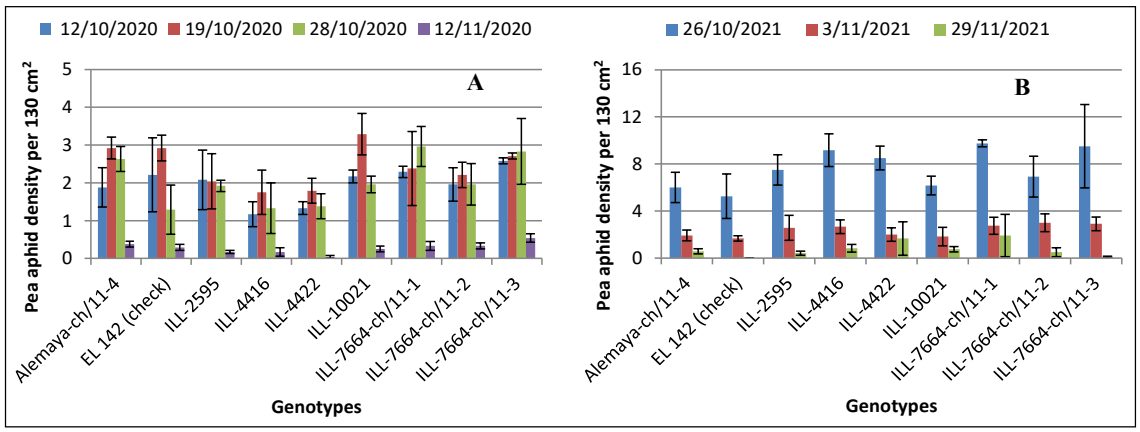


Fig 4: Occurrence of pea aphid (bars indicate standard error of mean) on pea aphid resistant and susceptible lentil genotypes at Akaki in 2020 (A) and 2021 (B) cropping seasons.

Table 4: Grain yield of pea aphid resistant lentil genotypes grown at Akaki site in 2020 and 2021 cropping seasons.

Genotypes	Grain yield (kg/ha) in a cropping season			
	2020 ($\overline{X}\pm SE$)	Yield reduction (%)	2021 ($\overline{X}\pm SE$)	Yield reduction (%)
Alemaya-ch/11-4	260.00^{ab} ±24.82	80.29	655.83^{ab}±61.42	93.01
ILL-2595	282.92^{a} ±64.26	81.89	542.08^{a-c}±62.09	91.54
ILL-4416	113.33^{b-d} ±27.29	54.78	-	-
ILL-4422	182.08^{a-d} ±6.31	71.85	373.75^{c}±53.18	87.74
ILL-10021	254.17^{ab} ±31.59	79.84	521.67^{a-c}±33.56	91.21
ILL-7664-ch/11-1	202.08^{a-d} ±23.83	74.64	615.42^{a-c}±11.76	92.55
ILL-7664-ch/11-2	97.50^{cd} ±18.41	47.44	414.17^{bc}±64.77	88.93
ILL-7664-ch/11-3	226.25^{a-c} ±42.52	77.35	763.33^{a}±75.06	93.99
EL 142 (check)	51.25^{d} ±1.25	-	45.83^{d}±6.71	-
CV (%)	28.2		16.5	-

*means followed by the same letters within a column are not statistically different at p=0.05.

does not discriminate between susceptible and resistant lentil genotypes during selection and feeding. This finding is in agreement with Edwards *et al.* (2003) who found that the related species *Acyrthosiphon kondoi* Shinji does not discriminate between susceptible and resistant Australian lupin (*Lupinus angustifolius* L. and L. luteus L.) varieties in both glasshouse and field trials. This might be due to presence of suitable signals from both susceptible and resistant lentil genotypes for host selection and feeding. Alternatively, as indicated above, the type of pea aphid resistance mechanism that exists in these pea aphid resistant lentil genotypes may not have affected host selection behavior, instead it might have deleterious effects on pea aphids that have accepted the host plant as a suitable feeding location. This deleterious effect was expressed as low pea aphid density on resistant genotypes, which was notable in seasons when the pea aphid density was high.

Although there was some variation in the density of pea aphid in some years and locations, the duration of infestation *i.e.* the number of days on which pea aphids fed on was similar for both susceptible and resistant genotypes. Moreover, at *Debre Zeit* in 2021 season unusually the pea aphid density increased in the second week of November after the crop matured. Thus, in this particular season the pea aphid infestation duration at *Debre Zeit* was unusually longer by two to three weeks than the preceding years. The exact reason for this extended period of infestation is not known.

Generally the pea aphid density at *Debre Zeit* and *Minjar* sites was greater than the pea aphid density at *Akaki* and *Chefe Donsa* sites. Moreover, the pea aphid population density reach maximum during the second and the third week of September in former locations and during the second and third weeks of October in the latter locations. This pea aphid density difference might be due to the warm temperature (due to low altitude) and to the early planting dates at *Debre Zeit* and *Minjar*. However, regardless of this difference, in each location and cropping season, although the initial date of infestation was variable, once infestation begins the pea aphid density/ population increases for about two to three successive weeks and then it crashes after reaching peak density. Although the causes of this pea aphid density crash has not been investigated, in northwestern Ethiopia and other countries pea aphid decline in field pea was associated with increase in minimum temperature, rainfall and relative humidity (Melaku, 2002; Karley *et al.,* 2004). In field pea, Maiteki *et al.* (1986) attributed this rapid decrease after the peaks to plant tissue senesce; to decrease plant nutritional quality; and increased natural enemy pressure. Contrary to this Pal *et al*. (2023) have reported positive association between aphid (*Aphis craccivora* Koch.) and natural enemy which might be attributed to the difference in test crop (*Pisum sativum* L.) and the aphid species. Other factors that contributes to the pea aphid seasonal crash are drought stress (McVean and Dixon, 2001) and high reproduction/ population density (McVean *et al*., 1999).

In lentil, Chowhan *et al.* (2022) have found negative association between aphid (*Aphis craccivora*) density and lentil grain yield. By the same token, a negative association between pea aphid density and lentil grain yield is expected. However, in this study, particularly in 2018 cropping season, despite the highest pea aphid density, the susceptible check EL-142 gave higher grain yield than the resistant genotypes and hence the percentage yield reduction was negative. Thus, the negative percentage yield reduction is not due to pea aphid attack on resistant genotypes. According to Erskine *et al.* (1994) simultaneous occurrence of multiple biotic and abiotic stresses on crops in the field is common and this makes difficult to create appropriate combinations of the resistances to different stresses within individual cultivars.

The limitation of this study was that the total number of pea aphids per 130 cm^2, which includes the different nymphal stages, apterous adults and alate forms, was counted. Resistant and susceptible genotypes have different aphid age structures and aphid age structure has been used to differentiate between resistant and susceptible genotypes (Edwards *et al.*, 2003). However, aphid age structure might not be important factor. For example, according to Das *et al.* (2022) pea aphid was unable to reproduce on pea aphid resistant lentil genotypes.

Resistant lentil genotypes to *Aphis craccivora* (Koch) and *A. kondoi* Shinji have been reported (Erskine *et al.,* 1994*).* However, this study reports the field resistance of lentil to pea aphid and thus it adds new knowledge on resistance of lentil to pea aphid under field/ natural infestation. The evaluation of resistance was based on pea aphid density and percentage yield reductions. However, it is known that plant resistance to insects is composed of different mechanisms such as antixenosis, antibiosis and tolerance. Thus, the identification of the mechanisms of resistance in these genotypes to pea aphid requires future research work. Besides, according to Sharma and Ortiz (2002), plant resistance to insects is relative and the level of resistance is expressed in relation to resistant and susceptible genotypes under similar environmental conditions.

CONCLUSION

The resistant lentil genotypes reduced the pea aphid density and gave higher grain yield than the susceptible check EL-142. These pea aphid resistant genotypes can be used independently during seasons when the pea aphid infestation is low. Or they can be combined with cultural practices to reduce pea aphid damage. Moreover, if insecticide application is required they can be treated at frequency much less than the frequency of insecticide application required to protect the susceptible check EL-142.

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Ethics and permissions

The author confirms there are no ethical considerations, permissions, or approvals required for the study to declare.

Conflict of interest

The author reports there are no competing interests to declare.

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