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Insecticidal and repellent effects of *Mentha longifolia* L. essential oil against *Aphis craccivora* Koch (Hemiptera: Aphididae)

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Abstract

Background Chemical control is generally used against aphids. The harmful effects of the chemicals used in the control on the environment and human health have contributed to the development of alternative control methods. The main objective of this study was to determine chemical composition of *Mentha longifolia* L. essential oil obtained from spontaneous plants in Algeria, investigate repellent and con-tact toxicity effect on *Aphis craccivora* Koch control, and assess the impacts of essential oil on development, survival and reproduction of *A. craccivora*.

Results The essential oil showed a concentration dependent significant toxic and repellent effects. The highest effect was recorded for 8 µl/ml concentration of essential oil. The repellent effect and mortality rate in 8 µl/ml concentration were 84.37 and 80.66%, respectively. The values of LC_{50} and LC_{90} were 1.848 and 26.782 µl/ml, respectively. The effect of essential oil on immature period, adult longevity, natal period, survival, and fecundity was statistically significant ($p < 0.05$).

Conclusions The findings in this study showed that the essential oil of *M. longifolia* harvested in the Tamanrasset region of Algeria has a toxic effect on *A. craccivora*, and can have a potential to be used as an insecticide to control *A. craccivora*. The use of environmentally friendly bioinsecticide will enable effective management of *A. craccivora*.

Keywords Botanical insecticide, Essential oil, Toxicity, Repellent, Aphid, Demographic parameters, *Aphis craccivora*, *Mentha longifolia*

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Graphical Abstract

Background

Aphids are important plant pests in agricultural production [1, 2]. The aphids retard plant growth by transmitting viruses, and also sucking out the sap, and significantly reduces crop yield [3].

Cowpea aphid (*Aphis craccivora* Koch, Hemiptera: Aphididae) is one of the polyphagous and cosmopolitan aphid species and was spotted in nineteen families with preference on leguminous plants [4]. The cowpea aphid is a harmful pest, and damage crops in open field and greenhouse by sucking the host sap, that is essential for plant growth. In addition, the pest indirectly damages to its host transmitting virus and producing honeydew [5]. The honeydew causes sooty molds that inhibit the photosynthesis activity of plants, and also mutualism with ants that can disrupt plant growth [6].

Several methods have been investigated to control aphids in different parts of the world. The aphids are commonly controlled using broad-spectrum chemical insecticides, which may cause the resurgence of target pests, secondary pest infestations, and the development of insecticide resistance in target pests [7]. In addition, the toxicity of pesticides has become a major environmental problem, as they are toxic to humans and many non-target organisms. Therefore, safe, inexpensive and environmentally friendly alternatives are needed to prevent the damage caused by excessive use of synthetic pesticides. Significant efforts have focused on plant-based natural substances as an interesting alternative [8]. Several studies have reported that essential oils derived from plants and considered as biopesticides could be employed in IPM programs to minimize the use of pesticide and manage the pest resistance [9, 10].

Plants of *Mentha* genus, spread worldwide, are belong to the Lamiaceae family and are represented by many species commonly known as mint. Most of plants in *Mentha* genus are known for their ability to generate a wide array of economically bioactive secondary metabolites [11]. The repellent properties, toxicity and some antifeedant activities of *Mentha* against various insects/pests have been studied [5, 12]. The effects of more than a thousand plants on insects have been studied, while only a few have actually been used in practice [13, 14].

Literature survey revealed that the insecticidal effect of Algerian *M. longifolia* essential oil on *A. craccivora* or any other aphids have not been studied yet. Furthermore, no experiments have been conducted to evaluate the impacts of Algerian *M. longifolia* essential oil on the demographic parameters of aphids. Few study on the insecticidal activity of *M. longifolia* essential oil has been reported against aphids [15, 16]. Therefore, due to the adoption of new eco-friendly aphid control strategies, the main objective of this study was to determine chemical composition of *M. longifolia* essential oil obtained from spontaneous plants in Algeria, investigate repellent and contact toxicity effect on *A. craccivora* control, and assess the impacts of essential oil on development, survival, and reproduction of *A. craccivora*.

Materials and methods

Plant material and essential oil extraction

Fresh leaves and stems of *M. longifolia* were harvested from Gueltate Afilal site in Tamanrasset region of the South Algeria and provided by Haggar National Park Office (OPNA). The species of this plant was identified by Dr. Rayane SAIFI and was confirmed by Mr. Mohammed BELGHOUL (Botanist chief curator). A voucher specimen (herbarium number: N°213/BH/SPF/SPDF/DEDPN/22) was deposited in the herbarium at Mr. Mohammed BELGHOUL.

In essential oil extraction, 100 g of air-dried plant materials were hydro-distilled for 4 h using a Clevenger-type apparatus. The extracted oil was drıed from the hydrolat using $MgSO_4$ by decantation [17]. The extraction was replicated five times, and the extracted oil was stored in the dark at 4 ℃. Essential oil yield was computed according to Carré [18] and expressed as a percentage to assess the efficiency of the extraction.

The physicochemical characteristics of *M. longifolia* essential oil were determined using the standards of the French Association for Standardization AFNOR [19]. The physicochemical characteristics determined were organoleptic properties, density, refractive index, pH, acidity index, and saponification index. In addition, 0.2 µl of the essential oil was injected to GC–MS with a column temperature varied between 50 and 250 °C at 5 °C/min. The essential oil was injected at 250 °C, and helium was used as the carrier gas (1 ml/min). The components of essential oil were identified based on retention time and mass spectra compared with the known compounds stored in the software database Libraries (NIST08, WILLEY8 and FAME) [20].

Test insect

Aphis craccivora used in the experiment were collected from an infected green bean field in Tazrouk (Tamanrasset) (23°24′51″ N and 6°15′47″ E) in 2021. The insects were reared on *Vicia faba* L. (Luz de'otono variety) and kept in a well-ventilated place allowing light to penetrate. Density of the aphids was maintained at low level. The aphids were transferred to the new plants at 2–3 leaf stage, every 15 days to avoid the appearance of alatae aphids responsible for the dispersal and emigration of colonies under the group effect [21].

Repellent effect

The repellent effect of *M. longifolia* essential oil against apterous adults of *A. craccivora* was evaluated according to the preferential zone method of filter paper described by Sayed et al. [16] with some modifications. Filter paper (Whatman No. 2 discs/9 cm in diameter) was divided into two equal parts. Five different essential oil concentrations (0.5, 1, 2, 4, and 8 µl/ml) were prepared by dilution in acetone. A quantity of 0.5 ml essential oil solution (Nt) was spread evenly on each half of the disc, while the other half received only 0.5 ml of acetone (Nc). Each concentration had four replications. The two halves of the discs were resoldered with adhesive tape after 15 min, and then placed in a Petri dish. The adult aphids of the same size were distributed in the center of each disc at a rate of 16 specimens per dish. Two hours later, the number of insects on each part treated with Nt and the number of aphids present on the part treated only with Nc were recorded. The average percent repellence (Pr%) for each concentration was calculated using the following equation:

$$Pr\% = \frac{(Nc - NT)}{(Nc + Nt)} \times 100$$

The repellent index (RI) was calculated to attribute the repellent effect of *M. longifolia* essential oil on *A. craccivora* adults using the following equation:

$$RI = \frac{2Nc}{(Nc + Nt)}$$

The essential oil was considered as repellent (*R*) if the mean RI was less than 1 − SD, otherwise the oil was considered as an attractant (A). The RI value between R and A was *I* defined as indifferent (*I*) [22].

Insecticidal activity of M. longifolia essential oil on Aphid adults by contact

Activities of the extracted essential oil on 30 adults of *A. craccivora* were tested in Petri dishes at 0.5, 1, 2, 4, and 8 µl/ml essential oil concentrations by direct spraying. Meanwhile, acetone 3% alone was used as a control. Each concentration had four replicates. The number of dead insects was counted after 3, 6, 12, and 24 h of exposure. Aphid mortality data were adjusted using correction formula of Abbott and lethal concentration 50 (LC_{50}), and 90 (LC_{90}) values were calculated using probit analysis [23, 24].

Insecticidal activity of M. longifolia essential oil on demographic parameters of the Aphid

From the apterous adults of *A. craccivora*, the newborn nymphs obtained 24 h later were transferred individually. Some nymphs were treated wih acetone used as the control treatment, while others were treated with different concentrations of essential oil (0.5, 1, 2, 4, and 8 µl/ml). A moistened cotton was placed undersurface of an uninfected apical leaf of *Vicia* to prevent the leaf from drying. These leaves were placed in petri dishes with multiple pinholes to allow aeration and guarantee the captivity of insects. The petri dishes were placed in a growth chamber following standard conditions for aphid culture (25 ± 3 °C, 40 ± 5% R.H with L16:D8 photoperiod). Each treatment started with 30 newborn nymphs produced in the growth chamber. The leaves were replaced as needed with fresh ones every 1–3 days. The nymphal development and productions were recorded every 24 h until the deaths of adults. The development period (mean ± SE) of the life stages, pre-reproductivity, reproductivity, adult longevity, survival, and fecundity was determined [25, 26].

Data analysis

Layout of all the experiments was completely randomized, with four replicates. Normality of the data tested using Shapiro–Wilk test [27]. The effects of essential oil concentration on repellent effect and insecticidal activity were assessed using a variance analysis (ANOVA). When the ANOVA indicated a significant difference between the treatments, Tukey's test ($p \leq 0.05$) was used to compare the mean values for different treatments. All statistical analyses were carried out using XLSTAT statistical software (Addinsoft, New York, USA).

Results

Essential oil analysis

The quantity of essential oil for wild mint obtained from the different extraction replications was the same. The average essential oil yield from aerial part of the plant was 1.49 ± 0.46%. The organoleptic and physicochemical properties provide a means of verification and quality control for the essential oil. The essential oil obtained was light yellow color, lipidic and liquid at room temperature. The smell of essential oil was agree-able, yet very strong and persistent. The values of density (*d*), pH, refractive index (*n*), acid-ity index and saponification index for essential oil quality are presented in Table 1.

The compounds of *M. longifolia* essential oil determined using GC-MS are presented in Table 2. Essential oil contained sixty-six compounds. The concentrations of Pulegone (31.85%), Carvone (23.18%), Isomenthone (13.53%) and Eucalyptol (5.72%) were higher compared to the rest of the compounds.

Repellent effect

The average repellent rate and index of *M. longifolia* essential oil against *A. craccivora* are given in Fig. 1 and Table 3. This natural substance had a significant repellent effect on adults of *A. craccivora*, and the repellent activity was improved with the increase in essential oil concentration. The repellent highest rate (84.37%) was recorded after 2 h for the highest essential oil concentration (8 µl/ml), while the lowest repellent rate (3.12%) was obtained for the concentration of 0.5 µl/ml (Fig. 1). Repellent index (RI) of essential oil demonstrated that the repellence (*R*) against *A. craccivora* was significant for 2 µl/ml and higher concentrations, while the repellence effect was indifferent (*I*) for the concentrations lower than 2 µl/ml (Table 3.).

Insect mortality bioassay by contact

The results of different concentrations of wild mint essential oil on the mortality rate of *A. craccivora* adults proved that the oil significantly affected the survival of *A. craccivora* after 24 h (F: 74.054, $p < 0.0001$, *df*: 119). The survival of aphids decreased with the increase of essential oil concentration and duration of exposure. The mean mortality rate recorded for the lowest and highest concentrations after 24 h were 28.66 and 80.66%, respectively (Fig. 2). The LC_{50} and LC_{90} values after 24 h of exposure were 1.848 and 26.782 µl/ml, respectively (Table 4).

Insecticidal activity on aphid demographic parameters

The mean duration effect of different essential oil concentrations on each nymphal stage of *A. craccivora* is summarized in Table 5. The impact of different concentrations on total duration of the immature stage was highly significant ($p < 0.0001$), nevertheless, the effect on the first three nymphal stages was slight. In addition, the duration effect decreased as the essential oil concentration increased.

Table 1 The physicochemical properties of wild mint (*Mentha longifolia*) essential oil

Parameters	*D*	*n*	pH	Acidity index (mg KOH/g oil)	Saponification index (mg KOH/g oil)
Values*	0.908 ± 0.010	1.518 ± 0.060	4.366 ± 0.057	1.086 ± 0.078	19.116 ± 3.457

* Values are the average of 3 measurements

Table 2 The compounds of wild mint (*M. longifolia*.) essential oil identified using GC-MS method

N°	Retention time (min)	Area%	Compound name
01	5.388	0.39	α-Pinene
02	5.859	0.06	3- Methylcyclopentanone
03	5.936	0.05	(E)-2-Hexenal
04	6.021	0.03	(S)-camphene
05	7.029	0.55	β-Pinene
06	7.154	0.16	β-Phellandrene
07	7.862	0.55	β-Myrcene
08	9.076	2.52	d-limonene
09	9.646	0.28	Cyclohexanone, 3-methyl-
10	9.878	5.72	Eucalyptol
11	10.193	0.03	Benzaldehyde
12	10.780	0.06	3- Octanol
13	3.604	0.03	Butanoic acid, 2-methyl-, 3-methylbutyl ester
14	13.785	0.03	Butanoic acid, 2-methyl-, 2-methylbutyl ester
15	14.150	0.07	2- Ethyl-2-hexenal
16	14.276	0.07	3- Ethyl-4-methylcyclotene
17	14.692	0.02	α-Undecene
18	14.899	0.04	3- Octanol acetate
19	15.069	0.02	Nonanal
20	15.388	0.14	Linalool
21	15.767	0.02	Limonene oxide
22	16.031	0.02	(E)-Limonene oxide
23	6.283	0.04	1,3-Dimethyladamantane
24	17.702	13.53	Isomenthone
25	18.365	2.76	Menthone
26	18.833	0.05	trans-P-Mentha-2,8-Dienol
27	19.028	0.38	α-Terpineol
28	9.111	0.34	Isoborneol
29	19.291	0.48	Isopulegon
30	19.770	1.46	3- Cyclohexene-1-carboxaldehyde, 1,3,4-trimethyl-
31	20.058	0.05	Hexyl isovalerate
32	20.227	1.79	Menthol
33	20.561	0.09	Dihydrocarveol
34	20.733	1.78	l-Dihydrocarvone
35	21.091	0.10	3,7-Undecanedione, 6,6,10-trimethyl-
36	21.980	31.85	Pulegone
37	22.794	23.18	Carvone
38	23.073	1.10	cis-Pulegone Oxide
39	23.427	0.22	Isomenthyl Acetate
40	23.603	0.65	Piperitone
41	23.732	0.42	Cyclohexene, 1-(1,1-dimethylethoxy)-6-methyl-
42	24.243	0.33	Cyclobuta [1,2:3,4] dicyclopentene, decahydro-3a-methyl-6-methylene-1-(1-methylethyl)-, [1S-(1.alpha.,3a.alpha.,3b.b
43	4.603	0.22	Dihydrocarveol Acetate
44	25.173	0.21	Carveol acetate
45	25.302	0.15	Isopiperitenone
46	25.681	0.05	Tridemorph
47	26.220	0.46	1- Cyclohexanone, 2-methyl-2- (3-methyl-2-oxobutyl)
48	26.834	0.07	4 (axial)-n-propyl-trans-3-oxabicyclo [4.4.0] decane

Table 2 (continued)

N°	Retention time (min)	Area%	Compound name
49	27.483	0.18	2- Acetyl-4,4-dimethyl-cyclopent-2-enone
50	28.388	3.72	Piperitenone
51	30.587	0.16	Carvenone oxide
52	31.466	0.25	γ-Cadinene
53	34.539	0.29	Benzofuran, octahydro-6-methyl-3-methylene-
54	34.835	0.05	(1H)-Naphthalenone, octahydro-8a-methyl-, cis-
55	36.214	0.15	3-Isopropoxy-1,1,1,7,7,7-hexamethyl-3,5,5-tris(trimethylsiloxy)tetrasiloxane
56	36.373	0.07	1H-Indene, 1-ethyloctahydro-7a-methyl-, (1.alpha.,3a.beta.,7a.alpha.)-
57	37.540	0.24	Pentanoic acid, 2,2,4-trimethyl-3-carboxyisopropyl, isobutyl ester
58	37.673	0.12	cis-1,4-dimethyladamantane
59	37.819	0.04	Cyclohexanone, 2,2-dimethyl-5- (3-methyloxiranyl)-, [2.alpha.(R),3.alpha.]–(.+–.)–
60	38.159	1.00	Caryophyllene oxide
61	38.767	0.67	Bicyclo [4.4.0] dec-1-ene, 2-isopropyl-5-methyl-9-methylene-
62	38.885	0.09	Mint furanone
63	39.441	0.09	H-Cycloprop[e]azulene, 1a,2,3,5,6,7,7a,7b-octahydro-1,1,4,7-tetramethyl-, [1aR-(1a.alpha.,7.alpha.,7a.beta.,7b.alph
64	40.583	0.07	1,1,1,3,5,7,9,11,11,11-Decamethyl-5-(trimethylsiloxy)hexasiloxane
65	43.551	0.17	1- Cyclooctene-1-carboxylic acid
66	46.771	0.02	Heptasiloxane, hexadecamethyl-
Yield: 1.49 ± 0.46%		Total identified compounds: 100%	

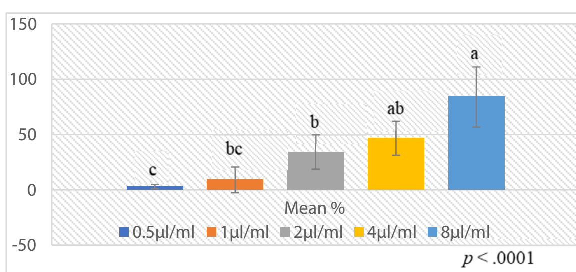

Fig. 1 Percentage repellence effects of essential oil concentrations against *A. craccivora* adults after 2 h of exposure; The mean value followed by the same letter was not statistically different ($p > 0.05$). The bar represents a standart deviation (SD)

The mean adult longevity of *A. craccivora* for 0.5 µl/ml essential oil treatment was 17.166 days and decreased to 1.2 days in 8 µl/ml concentration. The results revealed that total longevity of *A. craccivora* was strongly affected by the application of essential oil. The highest prereproductive and reproductive periods (3.2 and 13.966 days, respectively) were recorded in the lowest essential oil concentration tested, while the lowest values (0.633 and 0.566 days, respectively) were in the highest concentration tested. The highest total number of offspring per female of *A. craccivora* (37.566 nymphs) was obtained at 0.5 µl/ml essential oil treatment (Table 5). The results indicated a direct relationship between the essential oil concentration and the impact on various biological parameters of *A. craccivora*, and the impact was higher at the higher treatment concentrations.

Discussion

Several origins of wild mint plant have great morphological diversity expressed by more than 276 subspecies and varieties, of which the essential oil has subjected to

Table 3 Repellent effect (mean ± SE) of *M. longifolia* essential oil against *A. craccivora* adults after 2 h of exposure

Essential oil	Repellent index (RI) after 2 h of exposure (Mean ± SD)				
	Concentrations (µl/ml)				
	0.5	1	2	4	8
M. longifolia	0.969 ± 0.213^{I}	0.906 ± 0.120^{I}	0.656 ± 0.157^{R}	0.531 ± 0.277^{R}	0.156 ± 0.157^{R}

[*] *R* Repellent (RI less than 1 − SD), *I* Indifferent (RI in between 1 − SD and 1 + SD), *A* Attractant (RI greater than 1 + SD)

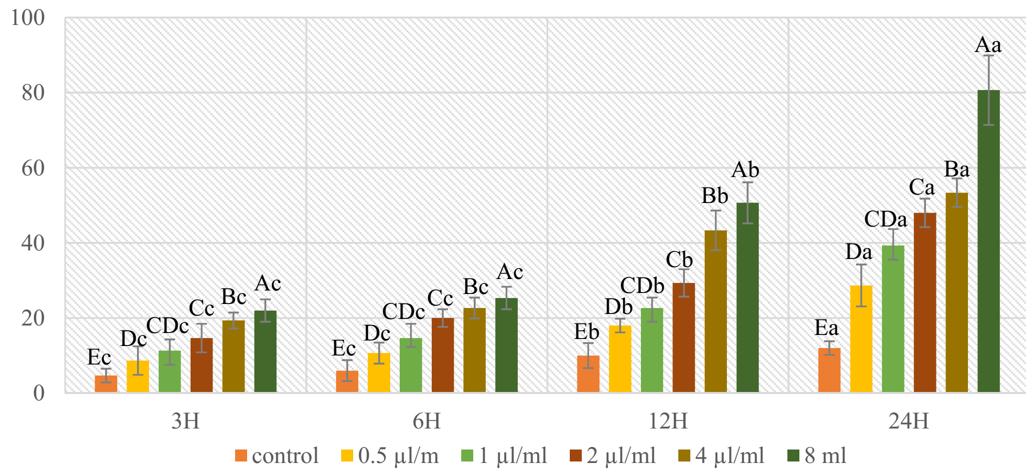

Fig. 2 Mean cumulative mortality rates of *A. craccivora* adults recorded following the treatments with essential oil of *M. longifolia*. The same upper and lower-case letters above the bars indicate no significant difference between the concentrations and the time, respectively. The bar represents a standart deviation (SD)

Table 4 Lethal concentration (LC_{50} and LC_{90}) for *A. craccivora* treated with *M. longifolia* essential oil

R^2	LC_{50} (µl/ml)	95% CI (µl/ml)	LC_{90} (µl/ml)	95% CI (µl/ml)	Slope ± SE
0.9481	1.848	1.084–3.150	26.782	15.710–45.660	1.103 ± 0.118

several studies [28]. The average essential oil yield tested in this study was different compared to the essential oil yield reported in different studies, while the yield was still within the range stated in the literature [29, 30]. The differences in essential oil yield could be attributed to variation in climatic and edaphic conditions, harvest season, stage of plant development, and cultivation practices, as well as the extraction method and the solvent used [13, 29]. The organoleptic properties of the essential oil are consistent with those obtained for *M. longifolia* essential oil from two Tunisian localities [15]. Identification of physicochemical properties is a mandatory step, but not sufficient, which helps explaining the chromatographic profile of an essential oil. The qualitative or quantitative chemical composition of *M. longifolia* essential oil varies drastically in. The pulegone was reported as the most abundant substance of *M. longifolia* essential oil [31–34]. Studies conducted in Iran, Greece, Tunisia and South Africa revealed that other dominant compounds of the essential oil are Ciscarveol (53–78%), Carvone (55%), Menthol (33%) and Menthone (31–48%), respectively [29, 35–38]. The insecticidal activities of plant oils have been attributed to some of the main chemical constituents [39]. The presence of more than one compound in

Table 5 Insecticidal effect of *M. longifolia* on biological parameters of *A. craccivora* (mean ± SE)

Biological parameters	Concentration (µl/ml)					
	Control	0.5 µl/ml	1 µl/ml	2 µl/ml	4 µl/ml	8 µl/ml
Nymph 1 (day)	1.333 ± 0.479^{A}	1.566 ± 0.504^{A}	1.6 ± 0.498^{A}	1.633 ± 0.490^{A}	1.433 ± 0.504^{A}	1.433 ± 0.678^{A}
Nymph 2 (day)	1.733 ± 0.449^{A}	1.533 ± 0.507^{AB}	$1{,}566 \pm 0.504^{AB}$	1.633 ± 0.490^{AB}	1.433 ± 0.504^{AB}	1.266 ± 0.639^{B}
Nymph 3 (day)	2.233 ± 0.727^{A}	1.966 ± 0.668^{AB}	1.533 ± 0.507^{AB}	1.566 ± 0.504^{B}	1.766 ± 0.817^{B}	1.633 ± 0.850^{B}
Nymph 4 (day)	3.133 ± 0.819^{A}	2.633 ± 0.808^{A}	2.1 ± 0.607^{B}	1.666 ± 0.606^{BC}	1.566 ± 0.568^{C}	1.233 ± 0.727^{C}
Total immature (day)	8.433 ± 1.006^{A}	7.7 ± 1.235^{AB}	6.8 ± 1.063^{BC}	6.466 ± 1.041^{CD}	6.2 ± 1.323^{CD}	5.566 ± 2.176^{C}
Adult prereproductive period (day)	3 ± 0.982^{A}	3.2 ± 0.805^{AB}	2.566 ± 0.727^{B}	1.8 ± 0.886^{C}	1.533 ± 0.899^{C}	0.633 ± 0.668^{D}
Reproductive period (day)	16.167 ± 1.20^{A}	13.966 ± 1.607^{B}	7.766 ± 2.344^{C}	5.733 ± 2.702^{D}	1.8 ± 1.270^{E}	0.566 ± 1.165^{E}
Adult longevity (day)	19.166 ± 1.205^{A}	17.166 ± 1.487^{B}	10.333 ± 2.411^{C}	7.533 ± 2.528^{D}	3.333 ± 1.935^{E}	1.2 ± 1.562^{F}
Fecundity (Nymph/Female)	45.033 ± 2.59^{A}	37.566 ± 1.675^{B}	23.333 ± 2.590^{C}	15.866 ± 1.30^{D}	12.366 ± 3.576^{E}	1.633 ± 2.525^{F}
Total longevity (day)	27.6 ± 0.621^{A}	24.866 ± 1.041^{B}	22.333 ± 1.154^{C}	16.833 ± 2.29^{D}	14 ± 2.228^{E}	8.4 ± 3.987^{F}

The same letters indicate no significant difference between the concentrations of each parameter independently the *M. longifolia* essential oil may be considered as an advantage in pest control. For this reason, studies should be conducted on the effect of *M. longifolia* essential oil on other plant pests.

The repellent properties of essential oils and extracts of the mint genus have been well-documented and proven against many pests [40], which has also been confirmed by this study. The repellent effect of *M. longifolia* essential oil on other aphids and pests, such as *Aphis punicae* Passerini and *Anopheles stephensi* Liston has proven [41, 42]. The repellent effect of *Allium sativum* L. and *Mentha piperita* L. essential oils on *A. craccivora* was 100% at the higher concentration than the essential oil concentrations tested in this study [43].

In our study, during the application of *M. longifolia* essential oil on *A. craccivora*, the LC_{50} value obtained after 24 h of application is 1.848 µl/ml. For Sayed et al. [16] and Zamani et al. [15], the essential oil extracted from the *M. longifolia* plant, respectively, gave an LC_{50} value against *A. punicae* of 2.4 µg/ml after 24 h of application and *Aphis gossypii* Glover of 0.059 µl/l after 72 h of application; this may be due to the behavior of the species against these oils as well as their genetics and morphology. Other researchers have studied the toxic effect of certain plant oils and other commercial liquid formulations against *A. craccivora*. Aziz et al. [44] studied the toxic effects of neem oil and cinnamic essential oil and found that mortality increased with dose and time, and LC_{50} values were 126.26 and 378.68 ppm after 7 days of application. For commercial liquid formulations of Nimbecidin, Green Miracle and their mixtures, the mortality rate of adults of *A. craccivora* increased with increasing application concentrations and the mixture of Nimbecidin (0.3 ml/l) with Green Miracle (3 ml/l) caused 100% mortality of *A. craccivora* after 3 days, while the mortality rate in separate treatments of Nimbecidin (0.6 ml/l) and Green Miracle (5.0 ml/l) was 100% after 5 and 6 days, respectively. LC_{90} and LC_{50} were 0.4 and 0.13 ml/l for nimbecidine, 3.5 and 1.7 ml/l for Green Miracle and 2.2 and 1.3 ml/l when mixing Nimbecidine and green miracle together [45]. Lethal toxicity depends on several factors, such as species studied, chemical composition, and experimental conditions [9]. The contact toxicity of essential oil on the same pest has been demonstrated in other studies. The LC_{50} value for *Pimpinella anisum* L., *Majorana hortansis* Moench, and *Citrus vulgaris* L. was of 5893.508, 6776.757, and 11530.09 ppm, respectively [46]. The results were in agreement with that obtained for *Eupatorium adenophorum* Spreng essential oil [47]. The concentrations of either LC_{50} or LC_{90} given in previous studies are higher than the concentrations obtained in this study. In addition, *M. longifolia* essential oil has also antimicrobial and antioxidant activities [35, 48], fumigant, and repellent effects on storage pests *Sitophilus zeamais* Motschulsky and *Callosobruchus maculatus* Fabricius [34, 39]. The effect of *M. longifolia* on different parameters of aphid development is consistent with those obtained with commercial liquid formulations of Nimbecidine and Green Miracle products and their mixtures regarding the impact on demographic parameters [32, 45]. The results revealed that *M. longifolia* essential oil could be used as an alternative in integrated pest control. However, further field experiments are needed to investigate the effects of *M. longifolia* essential oil on aphids and associated predators.

Conclusions

Bioinsecticides has an important role in future IPMs to manage insect resistance, to protect public health and to alleviate concerns on environmental pollution due to synthetic pesticide use in agricultural production. The findings in this study showed that the essential oil of *M. longifolia* harvested in the Tamanrasset region of Algeria has a toxic effect on *A. craccivora*, and can have a potential to be used as an insecticide to control *A. craccivora*. The use of environmentally friendly bioinsecticide will enable effective management of *A. craccivora*, and provide a safe environment, and enable high quality crops to be obtained.

Abbreviations

IPM	Integrated pest managements
RI	Repellent index
GC-MS	Gas chromatography–mass spectrometry
LC_{50}	Lethal concentrations 50
LC_{90}	Lethal concentrations 90
Nc	The number of insects on the part with any treatment
Nt	The number of insects on the part treated
Pr%	The average percent repellence

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Author contributions

RS, HS, MB and BM participated in setting the work planning and executing the experimental work and, was provided plant extracts for study. RS, HS, MB and IA analyzed the all data (statistical analyses) in study. RS, IA and AKA are the contributors in writing the manuscript. AKA, HS, RS and IA revised the manuscript. All authors read and approved the final manuscript.

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