Bioinsecticidal effect of *Lantana camara* and *Urtica dioïca* grown in northeast Algeria against *Plodia interpunctella* (Lepidopterae: Pyralidae)

Hami, M.[1]*, Zidi S.[2], Hamdiken, M.[2], Grara, N.[2], Atoki, A.V.[3] Messaoudi, M.[4]

ABSTRACT

To valorize both medicinal and aromatic Algerian flora, the present study was performed to assess the effective bio-insecticidal effect of essential oils extracted from the leaves of two aromatic and medicinal plants, *Lantana camara* and *Urtica dioica*, on the development and reproduction of *Plodia interpunctella* (Lepidoptera; Pyralidae) found in stored foodstuffs. *L. camara* extracts were found to have a higher level of essential oils (1.78%) than that of *U. dioica* (0.95%). In addition, the essential oils of *U. dioica* and *L. camara* revealed significant insecticidal activity with mortality rate of 84.44±5.09% (*U. dioica*) and 72.22±6.94% (*L. camara*). The lethal doses (LC_{50}; LC_{90}) for *U. dioica* and *L. camara* were respectively, 5µL/insect; 33µL/insect, and 9.12 µL/insect; 16.94µL/insect. The reproductive effects of essential oils of *U. dioica* were evidenced by the extended duration of nymphal development and the preoviposition period since those of *L. camara* were shown by an extension of the preoviposition period, a reduction of the oviposition rate and the duration of nymphal development. Further, results showed a marked decrease in the fertility and viability of the eggs laid by females, resulting in a reduction in reproductive efficiency. Analysis of the leaf powders revealed a potential insecticidal effect, proven by an increased mortality rate of up to 100% after 72 and 96 hrs of exposure.

Keywords: *P. interpunctella*, Essential oils, Plant powders, Bio-Insecticides, Biological parameters, *U. dioica, L. camara*

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INTRODUCTION

The increased demand for cereal products has led agricultural farmers to intensify their food crop productivity to ensure a permanent and sufficient food supply for the population. In Algeria, food security is a national priority and mainly targets basic foodstuffs such as cereals, whose production and conservation can be strongly affected by various biotic and abiotic factors (Aouadi *et al.,* 2020), including insects, causing a reduction in the quality and quantity of stored products. In this regard, losses estimated to be between 10 and 40% have been reported in global production (Bhumi *et al.,* 2017). The Indian meal moth, *Plodia. interpunctella* (Lepidopterae; Pyralidae) is a harmful insect that has long been known as a serious cosmopolitan pest of stored foodstuffs, particularly cereals, dried fruit, and similar products. Indeed, the larvae of *P. interpunctella* can cause important quality and quantity decreases in stored food products and subsequently marked economic losses for the agri-food industry in developing countries, including Algeria (Adarkwah et Schölle, 2012; Bouzeraa *et al.,* 2018). Accordingly, pest control processes are mainly based on the use of synthetic insecticides, the effectiveness of which has been known for more than 70 years (Boukraa *et al.,* 2022); however, the toxicological effects on human health, the environment, and non-target organisms limit their use (El Idrissi *et al.*, 2014; Hassani *et al.,* 2017). Recently, the use of safe health botanical bioinsecticides as alternatives has received great attention from agriculturalists owing to their effectiveness against a variety of target insects, in addition to their biodegradable properties, and their potential for use as part of integrated pest management (Benelli *et al.,* 2017; Ebadollahi *et al.,* 2017; Hategekimana et Erler, 2020; Sheng *et al.,* 2020; Aouadi *et al.,* 2020). Plants are natural sources of chemical substances, some of which are not directly beneficial to growth and development (Said-Alahl *et al.,* 2017). Additionally, plant essential oils (EOs) are natural secondary metabolite complexes that are synthesized by many families of aromatic plants (Myrtaceae, Apiaceae, Meliaceae, Lamiaceae, Asteraceae, Rutaceae, and Umbelliferae) in various vegetative organs (Benelli *et al.,* 2017; Ebadollahi *et al.,* 2017; Sheng *et al.,* 2020; Kheloul *et al.,* 2021), and are characterized by a strong odor, volatility, and generally a density lower than that of water (Bakkali *et al.,* 2008; Said-Al Ahl *et al.,* 2017). Essential oils are mainly composed of terpenes (monoterpenes, sesquiterpenes, diterpenes), oxygenated derivatives, and chiral molecules, including alcohols, aldehydes, esters, ketones, and phenols (Zuzarte and Salgueiro, 2015; Moghaddam and Mehdizadeh, 2017; Zouioueche and Couic-Marinier, 2021). Therefore, essential oils are widely used plant products because of their effective bactericidal, fungicidal, and insecticidal activities (Bakkali *et al.,* 2008; Delimi *et al.,* 2013; Sheng *et al.,* 2020). Consequently, scientists have focused on the use of aromatic and medicinal plants with efficient insecticidal activity; hence, their secondary metabolites have been used as botanical pesticides in the protection of stored plants and foodstuffs (Zandi-Sohani *et al.,* 2012) In this context, the present study used two aromatic plants to extract of essential oils (EOs) depending on their local availability and safety. Essential oils from *Urtica dioïca* (Urticaceae) (Bénani *et al.,* 2019) and *Lantana camara* (Verbenaceae) (Kruade *et al.,* 2010; Vadlapudi et Naidu, 2010) are widely used for culinary, medicinal, and insecticidal purposes. The insecticidal activities of *L. camara* essential oils have been reported for *Tribolium castaneum*, Sitophilus spp. (Zoubiri et Baaliouamer, 2012), and *Callosobruchus maculatus* (Zandi-Sohani et al., 2012). However, the insecticidal potential of *U. dioica* essential oils against stored product pests, especially adults of *P. interpunctella*. Thus, this study aimed to evaluate the bioinsecticide effectiveness of essential oils from *U. dioica* and *L. camara*, based on the determination of their LC_{50} and LC_{90} values, and to assess the toxicological effects of plant essential oils on some reproductive parameters of *P. interpunctella*, including the duration of nymphal development, period of pre-oviposition and oviposition, fecundity, and viability of eggs laid by females. The study also included a toxicological assessment of plant leaf powders on the survival of adult pests. Our results have shown that the essential oils of *U. dioica* and *L. camara*, tested on *P. interpunctella*, exhibit insecticidal activity and induce a very significant reduction in the rate of egg laying and hatching in treated females.

MATERIALS AND METHODS

Insects

The insect pests were obtained from Annaba mills and bred in the zoological and parasitological laboratory of our institution under optimal development conditions (27 °C and a relative humidity of 70%). The infested flour was placed in glass crystallizers and covered with tulle fabric fixed by an elastic band. The last-instar larvae were collected and placed in plastic boxes containing flour to activate pupation. Larval dating was displayed on days after nymph exuviations (Fasulo et Knox, 2018).

Plants

U. dioica leaves were collected in the region of Sedrata (Southwest of Souk Ahras City) in April 2023. Leaves of *L. camara* were collected in the region of Guelma City in March 2023. The leaves were washed, dried in the dark, and kept at room temperature until use.

Plant extractions and bio-insecticide evaluation

Essential oils were extracted from the dried and partially crushed leaves of *U. dioica* and *L. camara* by hydrodistillation according to the AFNOR standard protocol (1996) for an average of 3 h using a Clevenger-type system, in which three distillations were performed. In this study, 100 g of ground leaves was placed in a flask containing 700 ml of distilled water. The essential oils were evaporated along with water vapor, generated in a flask, and directed toward the neck of the swan connecting the flask with the refrigerant. The samples were then dehydrated with anhydrous sodium sulfate and stored in tightly closed actinide vials in a refrigerator at 4°C until use. The tested plant powders were obtained by grinding using an electric grinder. The ground material was then passed through a 0.5 mm diameter mesh sieve to obtain a fine powder with homogeneous particles. The essential oil yield is defined as the ratio between the weight of the product and the weight of the plants in the treatment as follows:

P% = (MEO /MPV)

Where

P-Yield of essential oils (%) per 100 g of dry matter.

MEO-Mass of essential oils obtained after distillation (g)

MPV-Mass of the used plant material (g)

Qualitative control of the essential oil promotes compliance with European or international standard guidelines. Different organoleptic characteristics (appearance, color, and smell) of the essential oils of the studied plants were examined.

Treatment

The essential oils of *U. dioica* and *L. camara* were administered separately via topical application (contact) to the ventral abdominal portion of newly exuviated pupae of *P. interpunctella* (age 0 days). After preliminary screening, the essential oils were applied at doses of 6, 8, 10, and 12µL/mL of acetone. All experiments were conducted at a constant temperature (25 ± 3°C), photoperiod of 8h light/ 16h dark, and a relative humidity of 60% ± 5. The tests were performed four times for each dose per 10 individuals. Acetone was chosen because of its rapid evaporation and lack of residual effects. The rate of growth and nymphal development was tested, and dead insects were counted every day until adults emerged. The observed mortalities (OM) were corrected according to the Abbott formula (Abbot, 1925), leading to the possibility of establishing a probit curve based on the decimal logarithm of the doses (Fisher, R. A. and Yates F., 1957). The decimal logarithm of the lethal doses LC50 and LC90 was determined for essential oils from the regression lines according to Finney's mathematical method (Finney, 1971), and the confidence intervals of LC50 and LC90 were then calculated using the Swaroop method (Swaroop et al., 1966) with a probability of 95%.

CM (%) = OM (%)−MC (%) *100/100−MC

Where

CM-Corrected mortality percentage, **OM-**Observed mortality in the test, **MC-**Observed mortality in controls

Eessential oils on the biological parameters of *P. interpunctella*

The essential oils of *U. dioica* and *L. camara* were applied to newly exuviated pupae females of *P. interpunctella* via topical application (contact) at concentrations corresponding to LC_{50} and LC_{90} values of each plant extract (5µL and 33µL/insect for nettle, and 9.12µL/ insect and 16.94µL/insect for Lantana), and the results were compared with those of the control untreated animals. Experiments were performed five times for each group of 10 insects. The effect of the used biopesticides on different biological parameters, including the duration of nymphal development (the duration in days separating the nymphal exuviation and adult exuviation), the preoviposition period (the number of days separating adult emergence and the start of laying), oviposition (the number of days of laying/female), and fecundity (the total number of eggs laid per female during the entire oviposition period), in addition to the viability of eggs laid by females (the number of eggs hatched among all eggs laid/female) were estimated.

Effect of leaf powders on adult mortality

The mortality rate of adults of *P. interpunctella*, aged 0 to 24 h, exposed to leaf powder of *L. camara* and *U. dioica* was determined in a group of 20 unsexed insects introduced into tightly closed jars containing 20 g of flour, mixed with the powder of *U. dioica* and *L. camara* leaves separately at four doses of 0.25, 0.5, 1, 2, and 4 g/20 g of flour, and the results were compared with those of the untreated control group placed in Petri dishes containing only pure flour. The experiments were conducted three times for each dose. Dead insects were counted after 24 h of contact for 4 days at the same 24-hour interval.

Statistical analyses

The bioinsecticide effects of the essential oils of *U. dioica* and *L. camara* on the biological parameters of *P. interpunctella* between groups were compared using different tests such as one and two classification criteria analysis of variance, Tukey's, and Student's (t) tests, in addition to linear regression. Statistical analyses were performed using the MINITEB software version 18. LC50 and LC90 values were calculated using probit analysis (IBM SPSS V20.0). The results for the control and treated groups are expressed as mean ± Standard Deviation (SD).

RESULTS AND DISCUSSION

Yield of essential oils and organoleptic characteristics

The EO yield of *L. camara* was slightly higher (1.78%) than that of *U. dioica* (0.95%). Many extrinsic and intrinsic factors can influence the total yield of essential oils. The originality of essential oils can be determined based on their organoleptic properties. The essential oil of Urtica dioica is mainly characterized by its fresh and highly unpleasant aroma, with a pale yellow to light green appearance. The essential oil of *L. camara* is yellow to orange in color, has an unpleasant smell, and a physiologically mobile liquid appearance. Like all essential oils, both should be used with caution and properly diluted to avoid any irritation.

Bioinsecticide activity of essential oils

The effectiveness of the essential oils was evidenced by the induction of mortality in the target individuals. The toxic effects of essential oils, based on the determination of the lethal concentration LC_{50} and LC_{90}, were shown by the inhibition of adult exuviation. As shown in Table 1; Fig 1, the essential oils induced a dose-dependent increase in the mortality of *P. interpunctella* adults and varied from one oil to another. Interestingly, the essential oil of *U. dioica* at the lowest dose (6µL/mL) caused mortality in *P. interpunctella* adults of 64.07±4.36%, whereas that of *L. camara* at the same dose induced only 20.74 ± 1.28% mortality. Whilst, at the highest dose (12µL/mL), the essential oils of *U. dioica* and *L. camara* induced a higher efficiency mortality percentage (84.44±5.09% and 72.22±6.94%, respectively) than that of the control

Eessential oils on nymphal development

The two test essential oils administered separately by topical application at LC_{50} and LC_{90} to pupae aged 0 days significantly affected the duration of nymphal development compared to the controls. The duration of nymphal development highly significantly extended (p=0.0001) in insects treated with plant essential oils at LC_{50} (13.6 ± 1.02 days) and LC_{90} (15.2 ± 0.75 days) as compared with controls (8.4 ± 1.02 days). Conversely, treatment with *L. camara* essential oils induced a highly significant reduction (p=0.009) in the pupal development duration to 6.8 ± 0.75, only for the highest dose (LC_{90}). The analysis of variance applied to the duration of nymphal development in the control and insects treated with nettle and lantana essential oils revealed highly significant (P=0.0001) and significant effects (p=0.002), respectively (Fig 2).

Table 1. Efficacy of *U. dioïca* and *L. camara* E. Os (µl/insect), applied topically to newly exuviated pupae of *P. interpunctella:* LC_{50} and LC_{90} probit analysis (CI: confidence interval).

Essential oils	Regression equation	Slope	LC_{50} (IC)	LC_{90} (IC)
U. dioïca	Y=1.6284 X+3.8042	3.82	5.73 (3.983 – 7.243)	33.11(24.56- 44.63)
L. camara	Y= 4.8717 X+0.2931	1.60	9.12 (7.47 – 11.26)	16.94 (13.88-20.66)

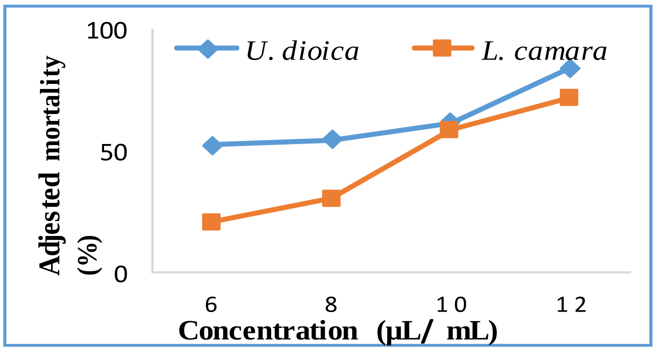

Fig 1. Effect of *U. dioica* and *L. camara* essential oils, administered by topical application to newly exuviated *P. interpunctella* pupae, on corrected adult mortality (m±SD, n=3 replicates containing each 10 pupae).

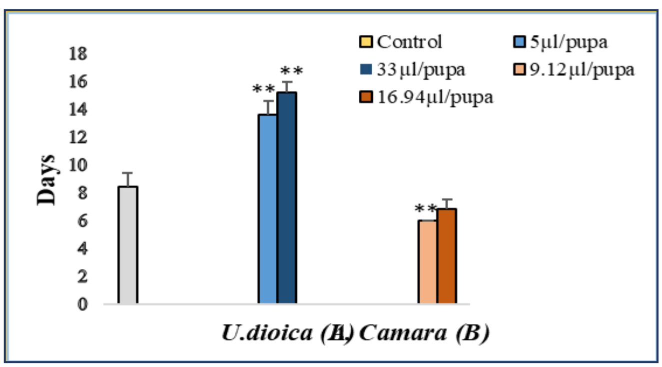

Fig 2. Effect of EOs (LC_{50}, LC_{90}) of *U. dioica* and *L. camara*, administered separately by topical application, on *P. interpunctella* pupae (0 days old), on the duration of pupal development (n=5 replicates containing each 10 pupae). m±SD.: mean± Standard Deviation; NS: Not significant; *: significant at 5%; **: significant at 1%; ***: significant at 1%.

Eessential oils on the oviposition periods

Under the laboratory experimental conditions (Temperature 27°C, relative humidity at 80%), egg-laying in *P. interpunctella* started from 0.7 ± 0.35 days after the emergence of adults and continued up to 3.40 ± 0.49 days in control females. *U.dioica* essential oils administered by topical application to newly exuviated pupae caused a significant extension of the preoviposition period ($p=0.017$) at the highest dose (LC_{90}) (Figure 3 A), and similarly *L. camara* essential oils significantly extended the preoviposition period ($p=0.021$), but significantly reduced the oviposition period ($p=0.016$) (Figure 3 B).

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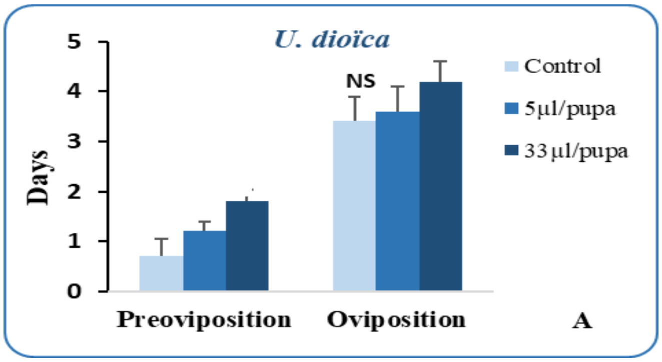

Fig 3A. Effect of *U. dioïca* (A) EO on oviposition and pre-oviposition periods (d) in *P. interpunctella* females treated topically with newly exuvied pupae (m ± s; n= 5 replicates containing each 10 pupae). m±SD.: mean± Standard Deviation; NS: Not significant; *: significant at 5%; **: significant at 1%; ***: significant at 1%.

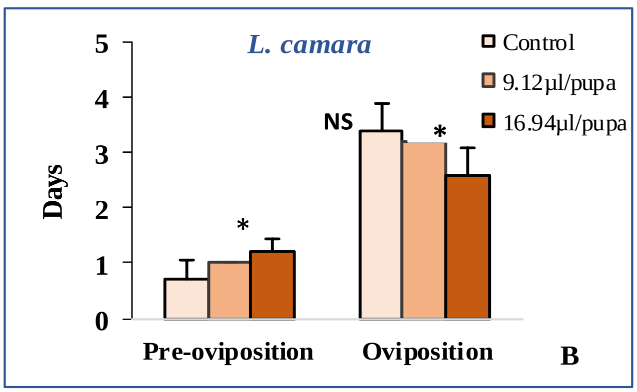

Fig 3B. Effect of *L. camara* (B) EO on oviposition and pre-oviposition periods (d) in *P. interpunctella* females treated topically with newly exuvied pupae (m ± s; n= 5 replicates containing each 10 pupae). m±SD.: mean± Standard Deviation; NS: Not significant; *: significant at 5%; **: significant at 1%; ***: significant at 1%.

Essential oils on the fecundity of *P. interpunctella*

As displayed in Fig 4, the number of eggs laid per female of *P. interpunctella* for the controls was 166.6±14.43 during the oviposition period, since that of treatment with essential oils of *U. dioica* and *L. camara* at LC_{50} was 106±15.32 eggs/female (Fig 4 C) and 40.8±6.46 (Fig 4 D). Meanwhile, the average number of eggs laid per female after treatment with plant essential oils at LC_{90}. highly significantly decreased (p=0.001) and reached 78.4 ± 9.79 eggs/female (*U. dioica*) and 26.2 ±7.11 eggs/female.

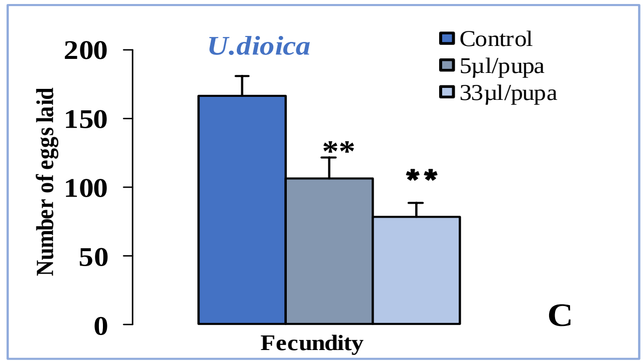

Fig 4C. Effect of *U. dioïca* (C) EOs (LC_{50} and LC_{90}) applied topically to newly emerged pupae of *P. interpunctella* on the fecundity (number of eggs laid/female; mean " SD; n = 6 females) m± SD.: mean± Standard Deviation; NS: Not significant, *: significant at 5%: significant at 1%; ***: significant at 1%.

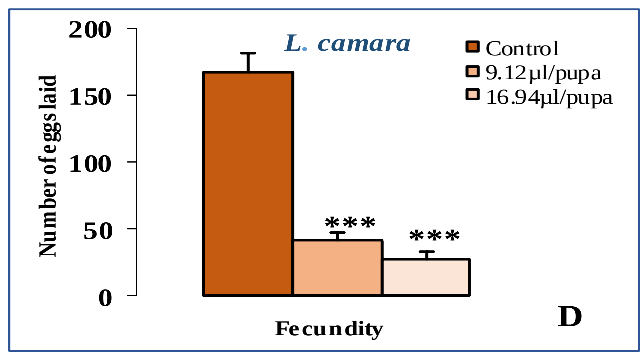

Fig 4D. Effect of *L. camara* (LC_{50} and LC_{90}) applied topically to newly emerged pupae of *P. interpunctella* on the fecundity (number of eggs laid/female; mean " SD; n = 6 females) m± SD.: mean± Standard Deviation; NS: Not significant, *: significant at 5%: significant at 1%; ***: significant at 1%.

Essential oils on the viability (%) of *P. interpunctella* female eggs

The viability of eggs laid by females was significantly (p<0.0001) decreased by the plant essential oil treatments at LC_{50} and LC_{90}. A regression ranged from 120.8±15.37% in the controls to 73.6±13.50% (*U. dioica*) and 16.8±5.77% (*L. camara*) in the plant essential oils treated animals at LC_{50} was noticed. Indeed, the egg hatching percentages were significantly reduced by up to 38% and 11% for the essential oils of *U. dioica* (Fig 5 E) and *L. camara* (Fig 5 F), respectively, compared to the controls.

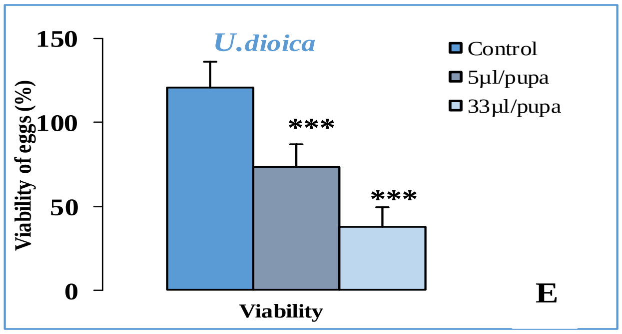

Fig 5E. Effect of *U.dioica* (E) EOs (LC_{50} and LC_{90}) applied topically to newly emerged pupae of *P. interpunctella* on the Viability (%; m ± SD; n = 5 replicates each of 10 eggs per dose). m± SD.: mean± Standard Deviation; NS: Not significant, *: significant at 5%; **: significant at 1%; ***: significant at 1%.

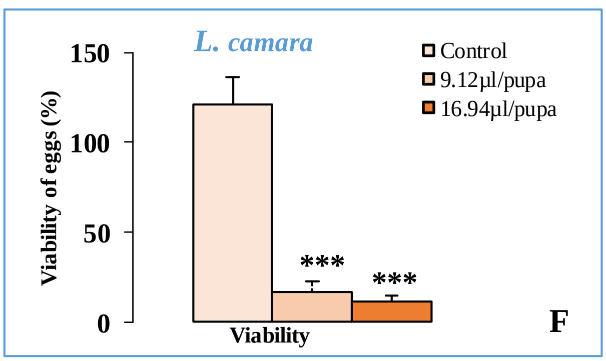

Fig 5F. Effect of *L. camara* (F) EOs (LC_{50} and LC_{90}) applied topically to newly emerged pupae of *P. interpunctella* on the Viability (%; m ± SD; n = 5 replicates each of 10 eggs per dose). m± SD.: mean± Standard Deviation; NS: Not significant, *: significant at 5%; **: significant at 1%; ***: significant at 1%.

Leaf powders of *L. camara* and *U. dioica* induced adult mortality

In Fig 6 and 7, the mortality rate of adults of *P.interpunctella* varied proportionally with the doses (0.25, 0.5, 1, 2, and 4g/20g of flour) of the plant and exposure periods (24h, 48h, 72h, and 96h). The groups treated with the plant powders at the lowest doses (0.25 and 0.5 g) after 24 h revealed a marked resistance with a mortality rate of 0%. The mortality percentage increased in animals treated with *L. camara* (M % = 43.33%) and *U. dioica* (M % = 60.22%) powders at the highest dose (4 g), reaching up to 95.30±5.32, and 86.66±4.71 for powders of *U. dioica* and *L. camara* powders, respectively, after 48h of exposure, and the maximum mortality percentage (100%) after 72 and 96 h at the highest dose (4 g). Interestingly, the absence of mortality recorded in the control animals proved the dose- and time-dependent insecticidal effect of the tested powders of *L. camara* and *U. dioica* against adults of *P. interpunctella*. The statistical analysis showed a highly significant difference between the mortality percentages of insect adults that received *L. camara* powders based on dose factor (F = 36.34, p=0.000) and exposure time factor (F = 26.48, P = 0.000). Importantly, the powder from the leaves of *U. dioica* had a highly significant effect on adult survival with F=89.77 and p=0.000 depending on the dose factor, and a highly significant variation with F=40.65 and p=0.000 depending on the time factor. These data highlight the great influence of these two factors in the mortality induction in adults of *P. interpunctella* treated with powder time (24,48,72 and 96 hours) (m±SD, n=3 replicates containing each 10 adults)

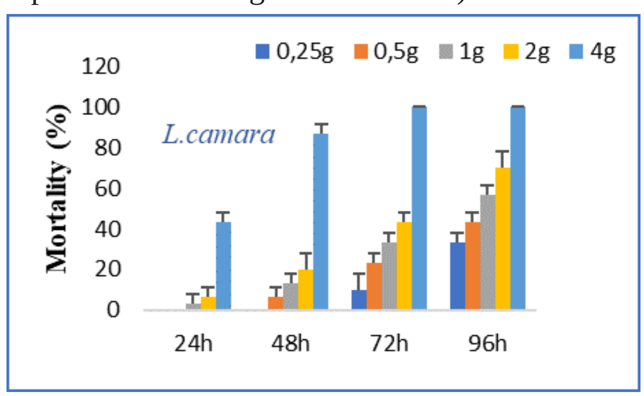

Fig 6. Effect of *L camara* leaf powder on the mortality of *P. interpunctella* adults (%) as a function of doses (g) and exposure time (hours).

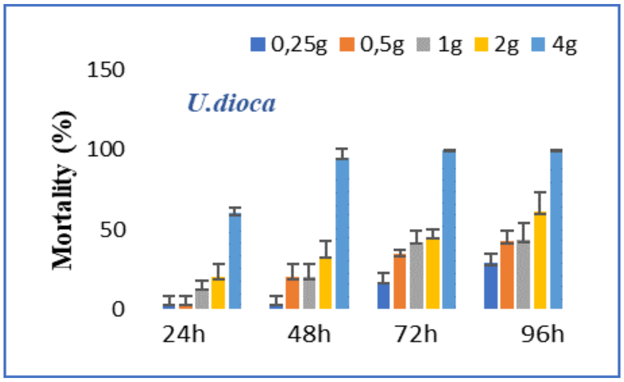

Fig 7. Effect of *U. dioica* leaf powder on the mortality of *P. interpunctella* adults (%) as a function of doses (g) and exposure time (hours)

Discussion

The yield of essential oils may be influenced by climatic factors, soil organic matter composition, and plant species. In our study, the yields of essential oils obtained using the hydrodistillation method varied between the two studied plants. The leaves of *U. dioica* exhibited a better yield (1.87%), while *L. camara* essential oil revealed an average yield of 0.95%. A similar study conducted by Khan *et al*., (2016) reported an essential oil yield of 0.06%, and 0.08% by weight (on a fresh weight basis, while Alitonou *et al*., (2002) have found a yield of *L. camara* essential oil as 0.21%, and a study conducted by Egyptian authors on essential oils of *L. camara* leaves have reported a yield around 0.36 (Mohamed, and Abdelgaleil, 2008) Accordingly, *U. dioica* essential oils have been reported to have efficient biological properties, along with an essential oil yield of 0.01% in dioecious nettle during distillation (Mohamed, and Abdelgaleil, 2008). However, Sitrallah and Merza (2018) reported a yield of 1.49% for essential oils from the same plant. This variability in essential oils between these plants, both in terms of their composition and yield, is likely due to the influence of different intrinsic factors that can specifically affect plant genetic material, in addition to extrinsic factors that may disrupt the conditions of plant growth and development (Derwich *et al*., 2015; Djouahri *et al*., 2015). Acute, sub-chronic, and chronic toxicological studies, even at the post-mortem scale, have become more interesting research areas. Hence, the assessment and characterization of the insecticidal potential of natural products using toxicological tests requires the determination of LC_{50} and LC_{90} values. Moreover, the essential oils extracted from the leaves of *U. dioica* and *L. camara* have a substantial insecticidal effect on the pupae and adults of *P. interpunctella*, as evidenced by the recorded mortality rate after topical application. Statistical analysis showed that the obtained mortality percentage varied proportionally to the concentrations used, and that the plant essential oils treated with *P. interpunctella* caused a dose-dependent increase in mortality rate. According to Kim *et al*. (2003) the toxic effects of essential oils depend on the species of insects and plants, treatment method, and exposure time. In this regard, the essential oil extracted from the leaves of *U. dioica* was found to be the most toxic, with an inhibition rate of adult exuviations exceeding 60% with the minimum dose (6µL/mL), and reaching a maximum rate of 84% with the highest concentration (12 µL/mL). This high efficiency could be due to the low LC_{50} value (5.73µL/mL) and LC_{90} (33.11µL/mL). Conversely, the mortality rates of insects treated with the essential oil extracted from *Lantana camara* showed marked toxicity at a concentration of 12µL/mL and a mortality rate of 72%, where the LC_{50} and LC_{90} values were respectively 9.12µL/mL and 16µL/mL. Our results are in agreement with those reported by numerous authors, who have reported the effectiveness of many essential oils as bioinsecticides. In fact, a study conducted by Benoufella-Kitous *et al*. (2019) on the toxic effect of *Urtica dioica* extract on *Aphis fabae* revealed good toxicity at doses of 10% and 20%. Similarly, Al-chalabi and Naji Taha (2017); Toubal *et al*. (2019) reported a cumulative effect of an aqueous extract of *Urtica pilulifer* used at different concentrations (4-16 mg/mL) on the mortality rates of different immature mosquitoes, *Culex pipiens* stages. In addition, Toubal *et al*. (2019) found efficient insecticidal properties in the aqueous extract and alkaloids of *Urtica dioïca* L, based on the LD_{50} values. Noteworthy, the aqueous extract, and the alkaloids induced efficient insecticidal activity against L4 larvae of 4,48 mg/mL and 4.48 mg/mL respectively, and 100% mortality after 24 hours of exposure time at the highest dose of 10%. Similar observations were made by Benani *et al.* (2019), who reported that an aqueous extract of *C. frustescens* (100 g/L) revealed a 16.35% reduction of the infestation rate of beans by bruchids. Furthermore, an increase in yield was recorded for the aqueous extract of *U. dioica* at a dose of 100 g/L, with a percentage of 4.96% and 8.18% at a dose of 200g/L. The essential oil extracted from *L. camara* indicated an insecticidal effect on inhibiting the emergence of *P. interpunctella* adults, which is in line with the findings of Zandi-Sohani *et al.* (2012), showing the effectiveness of this oil on adults of *Callosobruchus maculatus*. In addition, treatment with fumigation at the highest concentrations resulted in increased mortality rates of 23.6 to 100% in males and 14.1 to 97.1% in females (1160 µL/L). These results corroborate those of Zoubiri and Baaliouamer (2012) who reported a concentration-dependent increase in the mortality of *Sitophilus granarius* adults exposed to *L. camara* essential oil. Previous studies conducted by Bouda *et al.* (2001) revealed that *L. camara* essential oil caused a mortality rate of 100% at the highest concentration (0.5% v/w), and exhibited a potential insecticidal activity in the control of *Sitophilus Zea*. Moreover, the essential oils extracted from odorous plants have been reported to have insecticidal activity and effective toxicity towards stored food pests such as *E. kuehniella* (Delimi *et al.*, 2017), *P. interpunctella* and *E. kuehniella* (Bouzeraa *et al.*, 2018), *Sitophilus oryzae* (Hassani *et al.*,2017, and *Tribolium castaneum* (Bounechada *et al.,* 2011). Other studies have reported that *L. camara* can be used as an effective biopesticide, particularly against weeds. These data support a reduction in excessive use of synthetic herbicides (Mishra *et al.*, 2014; Talhi *et al.,* 2020). In our study, the essential oils tested at concentrations of LC_{50} and LC_{90} on newly exuviated pupae revealed a disruptive effect on the duration of the nymphal stage as well as on various reproductive parameters. Our results are in agreement with those reported by numerous authors, who have reported the effectiveness of numerous essential oils as bioinsecticides. In accordance with these data, Taibi *et al.* (2018) showed that the use of *O. vulgaris* essential oils lengthened the duration of nymphal development and the preoviposition period, and reduced the oviposition period and fecundity *of E. kuehniella* females. Likewise, Delimi *et al.* (2013) suggested white wormwood, *Artemisia herba-alba* essential oils, as reproduction-disrupting insecticides applied topically to pupae after their nymphal exuviations, which were considered effective insecticides. In this study, the tested essential oils revealed a significant bioinsecticide dose-dependent effect on the extension of the duration of pre-oviposition, the duration of nymphal development, and the reduction of the oviposition period. Rajashekaret *et al.* (2016). Chinensis eggs are sensitive to methanolic extracts of *L. camara*, which have been proven to have a protective effect against cereals by acting at different developmental stages of pests in stored foodstuffs. Recently, Viteri Jumbo *et al.* (2018) reported that the application of *Syzygium aromaticum* and *Cinnamomum verum* essential oils reduced female fecundity and growth of *C. maculatus*, even at sublethal doses. This was supported by a previous study (Soltani-Mazouni *et al.*, 2012; Delimi *et al.*, 2017; Bouzereaa *et al.*, 2018), which demonstrated the insecticidal effects of the essential oils of some aromatic plants on the reproductive potential of *P. interpunctella* and *E. Kuehniella* females. Our results align with studies that showed that even if the females manage to mate along with a prolonged laying period, the fecundity and viability of the eggs laid can be reduced compared to the controls because nettle essential oils cause a disturbance of egg laying in females of *P. interpunctella*. According to Kellouche and Soltani (2004), the reduction in fecundity is not only related to the reduction in the period of egg laying (oviposition) or survival of adult females, but can also be the result of a disruption in the vitellogenesis process. Aiboud (2012) found an important biological activity in the fertility of female *C. maculates*, as evidenced by a significant reduction in the number of eggs laid on grains treated with some essential oils. In addition, the powders of the two plant leaves showed an insecticidal effect on adults of *P. interpunctella* that were 0 days old. Based on the statistical analyses, significant dose and time-dependent variations in the mortality rates of the plant powders treated insects were observed, and the mortality rate reached 100% with the highest dose (4 g) in insects treated with the two plant powders for 72 and 96 h. However, the insecticidal effects of aromatic plant powders on stored food insects have been poorly investigated. Gakuru *et al*. (1995) found that *L. camara* is moderately effective in powder form, with a mortality rate of 29.6% for stored corn grain insect pests (*Zea mays*). In comparison with other previous studies, the use of dry leaves of *Ocimum canum*, dried whole or crushed from this plant inserted between layers of stored products, in general, was reported to induce a mortality rate of up to 100% in 24 h (Stoll, 2002); however, its long-term effectiveness has not been well established. Previous studies have shown that *Citrus lemon* powder effectively protected stored foodstuffs for six months of storage and thus led to reduced losses by 29.02% and 265.08 g of seed weight (Gakuru *et al*., 2011). In a study of the powders of three fragrant plants, *Corymbia citriodora*, *Cupressus lucitanica*, and *Tagetas minitiflora*. Kaloma *et al*. (2008) observed the effectiveness of *C. citriodora* powder on the conservation of corn with 4.45% attacked grains after eight months of storage. Similar results were reported by Kanana *et al*. (2018), who indicated the effective insecticidal activity of plant powders (*Corymbia citriodora*, *Tephrosia vogelii*, *Ocimum canum*, and *Capsicum frutescens*) in the conservation of corn seeds during storage against the maize weevil, *Sitophilus zeamais*. These results are in agreement with those recently reported by Ayalew (2020) who reported that the mortality induction in *Sitophilus zea* insects by leaf powder and essential oils extracted from *L. camara* is likely due to the presence of bioactive molecules and phytochemicals such as phytol, pyrroline, and 1-eicosanoid. ates in the field of efficient biological control.

AUTHOR CONTRIBUTION

Manel Hami: Conceptualization, Software, Methodology, Resources, Investigation. Writing - Review, Editing. Soror Zidi: Data Curation, Writing - Original Draft, Formal analysis. Malika Hamdiken: Investigation, Writing - Original Draft. Grara Nedjoud: Formal analysis, Resources. Ayomide Victor Atoki and Mohammed Messaoudi: Supervision, Validation, Project administration

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