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Effects of aqueous extracts of *Dittrichia viscosa* (Asteraceae) and insecticides on life history traits of *Chaitophorus leucomelas* (Insecta: Aphididae)

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Abstract: Methods used to control insect pests have been mainly chemical. Given the irritations associated with the use of pesticides, a search for alternatives is required, particularly through the use of plant extracts. The present study focused on comparing the insecticidal power of the aqueous extracts of the whole plant *Dittrichia viscosa* (commonly known as false yellowhead), the aqueous extract ratio of *D. viscosa*, and the bio-adjuvant *Silene fuscata* (1 : 1), as well as the synthetic pesticides Thiamethoxam/Lambda-cyhalothrin. Abundance, fecundity, demographic parameters, and biochemical parameters (lipid-glucidic biomarkers) of the winter phenotype of the black poplar leaf aphid *Chaitophorus leucomelas* were considered variables to assess the effectiveness of different approaches. The results show a strong effect of the aqueous extracts of *D. viscosa* (A.E. Plant) on abundance, with pronounced insecticidal activity from the aqueous extract ratio (A.E. Ratio) ($P < 0.05$). The lipid and carbohydrate energy of sexuparae undergo significant changes depending on the products used, with a disturbing effect of the synthetic product compared to aqueous extracts ($P < 0.05$). Fecundity shows a remarkable disturbance under the action of the active ingredient compared to the extracts. The results confirm that the products applied cause a disturbance in the growth rate (r_m) and net reproductive rate (R_0) of sexuparae, with the chemical treatment having the strongest effect ($P < 0.05$). The full dose of the active ingredient causes remarkable disturbances in the multiplication rate (λ) and the mean generation time (T) of the sexuparae compared to the other applied molecules. Some stability is reported for the doubling time (DT) of treated females compared to the control ones.

Keywords: abundance; aphid; biological control; demographic parameters; energetic biomarker; *Populus nigra*

The black poplar leaf aphid, *Chaitophorus leucomelas* (Koch, 1854) (Hemiptera: Aphididae, Chaitophorinae), is one of the most important pests of black poplar *Populus nigra* (L., 1753) (Salicales: Salicaceae) (Chararas 1972; Nef & Janssens 1982; Barrios-San et al. 2014). It causes direct damage to the host plant by extracting its sap, which leads to a growth restriction of up to 15%, and indirect damage by transmitting viruses and excreting honeydew, a favourable environment for fungal devel-

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opment (Ramírez & Verdugo 2008; Dedryver et al. 2010; Rubio-Melendez et al. 2011). Like most aphids, *C. leucomelas* is mainly controlled by synthetic pesticides. However, their massive use leads to multiple dysfunctions in agroecosystems, including the emergence of resistance (Van den Bosch & Gilligan 2008; Hazarika et al. 2009), resurgence or appearance of new pests (Hardman et al. 1991; Hazarika et al. 2009) and the destruction of beneficial organisms (Desneux et al. 2007; Marins et al. 2021). To restore this situation, operators in the field of plant protection have turned to biological control (Hågvar & Hofsvang 1991). In this context, the potential of botanical insecticides nowadays represents an effective and non-polluting means of control. Substances of plant origin have long been a major source for developing new substances with biocidal properties (Gomez et al. 1997). Several authors suggest that essential oils or plant extracts are promising for controlling insect pests (Ngamo & Hance 2007). *Dittrichia viscosa* (Greuter, 1973) is an invasive plant belonging to the Asteraceae family (Omezzine et al. 2011; Zouaghi et al. 2021; Bellik & Mekhoukh 2023). It has been frequently used in traditional pharmacopoeia for various therapeutic purposes. Many compounds have been identified and isolated from this plant, such as flavonoids (Hernández et al. 2007), monoterpenes (Pérez-Alonso et al. 1996), condensed tannins (Rhimi et al. 2017), triterpenoids, lactones, and sesquiterpene acids, including ilicic acid (Fontana et al. 2007) and polyphenols (Danino et al. 2009). Extracts of *D. viscosa* have shown phytotoxic (Levizou et al. 2002), antifungal (Cohen et al. 2002; Moussa et al. 2018), nematocidal (Oka et al. 2001), acaricidal (Mansour et al. 2004), and insecticidal effects (Alexenizer & Dorn 2007; Gueribis et al. 2019). Perdikis et al. (2007) report that *D. viscosa* exhibits major biocidal activity against aphids. In addition to reducing the availability, the intrinsic toxicity of active ingredients can affect the energy balance and demographic parameters of pests. This toxicity can produce biochemical, histological, or morphological disturbances, resulting in specific alterations of an organ, a system, or a function, or of a biochemical or biological process (Moussavou Moudouma 2010; Louat 2013). Some authors argue that the observed variations in the major life characteristics of organisms can be explained by life history theory. This theory is based more specifically on the characters having a direct link with reproduction or survival, such as size at birth, size and age at sexual maturity, the number of offspring produced, and their ability to survive (Stearns 1992; Roff 2002, as cited in Giron 2006). Facing different stressful conditions, the organism must arrange the various life history traits involved, based on the available energy level (Levins 1968). Molven & Goksoyr (1993) report that organisms employ different means to restore homeostasis, and that all responses appear to technically incur a cost to the organism, particularly in terms of metabolic resources, such as sugar and lipids. Additionally, Lagadic et al. (1997) confirm that assessing disturbances at the organism level requires the study of biomarkers. This latter makes it possible to describe, explain and even predict the disturbance effects of different stressful states. The objective of the present study is to evaluate the effects of aqueous extracts of *D. viscosa* in combination with a bio-adjuvant *Silene fuscata* and a synthetic pesticide (Thiamethoxam/Lambda -cyhalothrin) on the abundance, energy balance (lipid and carbohydrate biomarkers), and certain demographic parameters such as fecundity, net reproductive rate (R_0), intrinsic rate of increase (r_m), finite rate of increase (λ), mean generation time (T), and doubling time (DT) of the black poplar leaf aphid, *Chaitophorus leucomelas*.

MATERIAL AND METHODS

Geographical location of the study region. The present study was conducted in 2012 in the middle of the Mitidja plain (80 to 100 m a.s.l., 2°45' E, 36°35' N) in the Soumâa region (Algeria), at the piedmont of the Atlas Mountains in Blida province (Loucif & Bonafonte 1977). Precipitation fluctuates largely, varying between 380 mm and 787.88 mm, and occurs primarily during winter and spring. The coldest months are January and February with average temperatures of 4.49 °C and 4.48 °C, respectively. The hottest months are July and August, with respective average temperatures of 37.2 °C and 37.0 °C for the period from 1997 to 2012. For the study year 2012, the coldest temperature was recorded in December, with an average value of 11 °C, while the hottest temperature was recorded in July at 33.2 °C. Emberger's Bioclimatic Quotient Q2 (Sauvage 1963) classifies the Soumâa zone as being in the humid bioclimatic stage with mild winters. In this region, two artificial

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poplar groves with 8-year-old black poplar *(Populus nigra)* were chosen for the study.

Preparation of the aqueous extracts. The plant material selected for the aqueous extract preparation consisted of only two common spontaneous plants in the Mediterranean region: *D. viscosa* (Asteraceae) and *S. fuscata (Link ex Brot., 1804)* (Caryophyllaceae). The first species, *D. viscosa* was used as an active ingredient; it was collected in the flowering stage of the sub-littoral region of Soumâa (Algeria) during the summer period. The second species, used as a bio-adjuvant for the first time, was collected at the flowering stage during the autumnal period in the mountainous region of Chrea (Algeria) (980 m a.s.l., 2°52' E 36°25' N). The precipitation, mainly in winter and spring, was characterised by significant interannual and intermonthly irregularity, varying between 1 225.38 mm and 360.83 mm. Regarding temperature, the coldest month recorded was January (Tm_{min} = 1.01 °C), while the hottest month was July with a (Tm_{max} = 31.37 °C). Emberger's Bioclimatic quotient (Q2 = 83.44) classifies the Chrea region in the sub-humid bioclimatic stage with mild winters (Sauvage 1963). The collected plants were cleaned and dried in the open air, away from light and moisture. The plant material, after drying in the shade, was crushed into a powder using a propeller mixer (Moulinex). An aqueous maceration was performed using 20 g of vegetable powder and 250 mL of distilled water. The bottles were horizontally agitated for 72 h at room temperature. The homogenates were first filtered with compresses, then through Whatman paper (N° 1). The aqueous extracts obtained were preserved aseptically in 25 cm^3 Roux bottles, surrounded by aluminium foil to prevent degradation of the molecules by light, and then stored in a refrigerator at + 4 °C for later use (De Souza et al. 1995).

The synthetic material. The pesticide used for comparison is a product based on two active ingredients (thiamethoxam/lambda-cyhalothrin), belonging to two different chemical families: neonicotinoids/pyrethroids, with the crude chemical formulas $C_8H_{10}ClN_5O_3$ and $C_{23}H_{19}ClF_3NO_3$, respectively. The molecule has three modes of action (contact, ingestion and systemic) by blocking membrane permeability and the opening of sodium channels (Couteux & Lejeune 2012). The synthetic material was obtained from the Phytopharmacy Laboratory of the Department of Biotechnology, Faculty of Natural and Life Sciences, Blida 1 University (Saad Dahleb), Algeria.

Sampling and Treatment. Treatments were focused on the different stages of *C. leucomelas* growing on *P. nigra* leaves during the autumn-winter period. Two poplar groves were set aside for the efficacy tests. Two supply modes of aqueous extracts were applied: aqueous extracts of the whole plant *D. viscosa* and an aqueous extract ratio of *D. viscosa* and *S. fuscata* (1 : 1). For the active ingredient, we used the prescribed doses 1 (D1 = 4 mL/L) and 2 (D2 = 2 mL/L). As for the control (C), a spray of running water was applied. A linear device with observation plots proposed by Frontier (1983) was used. From the 21 trees observed in the plots, we collected five leaves from each cardinal direction at a rate of one sample per day from the eight randomly selected trees across the different blocks. The samples were taken over a period of 11 days, from November 30, 2012, to December 9, 2012. All samples were taken at man height (170 cm). Samples taken from the field will undergo an abundance assessment in the laboratory. Living females are weighed and placed in 1.5 mL Eppendorf tubes (Eppendorf, Germany), then stored at –20 °C for a quantification of the energy balance.

Estimation of the abundance. The counting technique of individual aphids, obtained through plant transects, consists of taking leaves from each cardinal point during the period of investigation, which lasted over one month. The different life stages (larvae and adults) were then identified and counted under a magnifying binocular microscope (G × 40).

Estimation of the conditioning. From the residual populations, we were interested in estimating the weight of females. Ten females were placed in 1.5 mL Eppendorf tubes (previously tared) and then weighed. The weight measurements of the females were done using an accurate balance.

Estimation of the energy balance. The preserved females were subjected to the quantification of lipid and carbohydrate energy biomarkers, following the protocols established by Van Brummelen & Suijfzand (1993) and Win Decoen (2000), as reported in Mostefaoui et al. (2014), respectively. The extraction of lipid reserves is carried out after crushing of *C. leucomelas* (10 individuals per tube) with a monophasic mixture 1 : 2 : 0.8 (chloroform : methanol : double-distilled water). The tubes are centrifuged for 5 min at 14 000 revolutions/min

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at 4 °C. Adding chloroform to the tubes separates the mixture into two phases. The chloroform solutions containing the lipids are recovered and pooled, then dried over sodium sulfate. The lipids are recovered after rinsing the sodium sulfate with chloroform. The tubes are evaporated to dryness under a stream of nitrogen. Sulfuric acid is added to the dry residue, and then it is heated for 10 min at 100 °C. After cooling, the vanillin reagent is added to each sample. The solution then assumes a pink colour, and the optical density is measured at 540 nm after 10 min. The white colour is obtained by mixing a series of cholesterol concentrations with sulfuric acid and vanillin as a reagent. Regarding the extraction and quantification of carbohydrate reserves, *C. leucomelas* individuals are homogenised in double-distilled water using a grinder, then trichloroacetic acid (T.C.A., 15%) is added to precipitate the proteins. Precipitation is facilitated by centrifugation for 10 min at 3 000 revolutions/min at 4 °C. The sugar-containing supernatant is recovered, and the pellet is redissolved in a 5% T.C.A. solution. A solution of 250 µL containing the supernatants is poured into a test tube, to which 250 µL of 5% phenol and 1 mL of sulfuric acid (H_2SO_4) are quickly added. The mixture is placed in a well of a microplate in the light and at room temperature. Sample adsorption is measured after 30 min at 490 nm. The white colour is obtained from a stock solution of glucose at 0.5 mg/mL (5 mg of glucose in 10 mL of distilled water).

Estimation of the fecundity. Fecundity is measured as the ratio of the number of larvae to the number of female adults (Carey 1982).

Estimation of the reproduction parameters. The sexuparae of *C. leucomelas* are only represented by females in this phase of their development cycle. Before applying the active molecules, 20 leaves were randomly taken from which we kept one nymph and one adult per leaf (Tahriri Adabi et al. 2010). After 24 h of treatment, the nymphs and adults on each leaf were checked daily, and their survival was recorded at each of the different experimental units. The presence of exuviae was adopted to determine the moulting period. When nymphs developed into adults, daily monitoring was conducted to estimate survival and reproduction rates. We took measures to remove all the neonate larvae from the leaves after counting them. These observations were maintained for 10 days after the treatments were applied. Demographic parameters of *C. leucomelas,* such as Net Reproductive Rate (R_0), Intrinsic Rate of Increase (r_m), Finite Rate of Increase (λ), mean generation time (T) and Doubling Time (DT) were calculated according to the formulas proposed by Carey (1982) and Gul et al. (2021).

Data analysis. The statistical analysis involved evaluating the insecticidal activity of aqueous extracts on the abundance of *C. leucomelas*. Variance analyses were performed on homogeneous means, adopted based on a coefficient of variance (CV) < 15%. Comparisons of the mean abundances and energy biomarkers of the aphids were performed using Wilcoxon tests. The cross-correlation test was used to investigate the relationship between the order of inflow and toxicity. Under the influence of various applications, the statistical description of the temporal variation trends in fecundity and demographic parameters was established using the ANOVA test. The significant contributions were retained at a threshold probability of 0.05, and the calculations were carried out using the PAST software (version 1.37) (Hammer et al. 2001).

RESULTS

Assessment of the impact of aqueous extracts and synthetic pesticides on *Chaitophorus leucomelas* abundance. With reference to the abundances, the results indicate that the aqueous extracts have a validated toxicity on *C. leucomelas* individuals compared to the control group ($P < 0.05$). The low median values recorded in the treated samples confirm the pronounced insecticidal activity of the aqueous extracts in the phytopreparation ratio (median = 14) ($P < 0.05$). The cross-correlation test shows a non-significant time lag (temporal offset) of no more than two days (1.79 days) between the phytopreparation-treated and control populations ($P < 0.05$). The same test shows that the reestablishment of maximum abundances (barycenter) indicates a significant time lag following the effect of phyto-preparations ($P < 0.01$) (Table 1). The insecticidal activity of both the full-dose and half-dose treatments is very distinctive in terms of abundance reduction of sexuparae, with mean values of 126.36 ± 6.70 and 144.81 ± 14.47, respectively, compared to the control group, which exhibited a mean of 469.45 ± 71.88 ($P < 0.05$). In contrast, the comparison of abundances under

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the dose and half-dose effect revealed no significant difference ($P > 0.05$). The medians show the lowest values under the synthetic product effect ($P < 0.05$). The cross-correlation test reveals a significant temporal shift (3-day lag) between the treated and control groups ($P < 0.05$) (Table 1).

Estimates of the effect of aqueous extracts and pesticides on demographic parameters. Following exposure to the active ingredient, fecundity undergoes a gradual reduction until the fifth day, with a striking and disturbing action of the prescribed dose (D1 = 4 mL/L) compared to the half-dose (D2 = 2 mL/L). Beyond this period, a gradual recovery of biotic potential is noted, and it continues until the end of the experiment (Figure 1A). On the other hand, the biotic potential better tolerates the effect of phytopreparations, whose aqueous extract ratio engages a very pronounced disturbance of fecundity compared to aqueous extracts of the whole plant (Figure 1B).

The results of the ANOVA-type variance analysis, supported by a post-hoc test, indicate that the Net reproductive rate (R_0) of females exposed to phytopreparations (E.A. plant = 2.862 ± 0.252; E.A. ratio = 2.085 ± 0.463) and to the active ingredient (half-dose = 2.702 ± 0.471; full-dose = 1.603 ± 0.541) is significantly lower compared to the control group (5.081 ± 0.561). Insignificant values are indicated by the comparison of the reproduction rate under the effect of aqueous extracts of the whole plant *D. viscosa* and the ratio *D. viscosa/S. fuscata,* and the dose and half-dose of the synthetic pesticide. Regarding the intrinsic rate of increase (*rm*) of *C. leucomelas* populations, analyses indicate a significant increase between the treated and control groups. This increase is particularly pronounced when synthetic products are compared to the effects of aqueous extracts of phytopreparations. Moreover, the synthetic pesticide applied, the prescribed dose (D1) and the aqueous extract of the ratio clearly reduced the multiplication rate (λ). The same results show that the homologous dose continues as a treatment, significantly affecting the mean generation time (*T*) of *C. leucomelas*. Finally, the different types of treatment have a minimal impact on the doubling time (*DT*) of populations (Table 2).

The effects of treatments on biochemical and weight traits of *Chaitophorus leucomelas.* Table 3 shows the lipid-carbohydrate energy balance and the weight variation of *C. leucomelas* females after applying phytopreparations and active ingredients. The results clearly demonstrate the dis-

Table 1. Phytopreparation effect of *Dittrichia viscosa*, *Silene fuscata* and thiamethoxam/lambda-cyhalothrin on the abundance of *Chaitophorus leucomelas*

Treatments	Mean ± SE	Median	Wilcoxon test	Cross-correlation test		
				Barycentre	Lag	*P*-value
Control	219.72 ± 46.07[a]	138	0.007**	4.73	1.38	0.337[NS]
Aqueous extract of the plant	55.00 ± 9.27[b]	26		3.35		
Control	219.72 ± 46.07[a]	138	0.005**	4.73	1.79	0.337[NS]
Aqueous extract of the ratio	47.54 ± 10.61[b]	14		2.94		
Aqueous extract of the plant	55.00 ± 9.27[a]	26	0.029*	3.35	0.41	0.001**
Aqueous extract of the ratio	47.54 ± 10.61[b]	14		2.94		
Control	469.45 ± 71.88[a]	465	0.007**	4.62	2.92	0.010*
Half-dose	144.81 ± 14.47[b]	15		1.64		
Control	469.45 ± 71.88 [a]	465	0.007**	4.62	2.95	0.025*
Dose	126.36 ± 06.70[b]	19		1.67		
Half-dose	144.81 ± 14.47	15	0.202[Ns]	1.64	0.30	0.081[NS]
Dose	126.36 ± 06.70	19		1.67		

NS – non-significant; * significant at 0.05; ** significant at 0.01; *** significant at 0.001; different letters indicate differences among groups control, aqueous extract of plant *D. viscosa*, aqueous extract of ratio (*D. viscosa/ S. fuscata)*, half-dose of active ingredient, dose of active ingredient; SE – standard error

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Table 2. Demographic parameters of *Chaitophorus leucomelas* under the effect of biological and chemical treatments

Parameters	Net reproductive rate (R_0)		Intrinsic rate of increase (r_m)		Finite rate of increase (λ)		Mean lifetime (T)		Doubling time (DT)	
Treatments	Mean ± SE	*P*-value	Mean ± SE	*P*-value	Mean ± SE	*P*-value	Mean ± SE	*P*-value	Mean ± SE	*P*-value
Biological										
Control	5.481 ± 0.271^{a}	0.000***	0.021 ± 0.012	0.293^{NS}	0.691 ± 0.012	0.212^{NS}	2.632 ± 0.071	0.996^{NS}	2.171 ± 0.131	0.654^{NS}
Aqueous extract of the plant	2.862 ± 0.252^{b}		0.011 ± 0.011		0.634 ± 0.011		2.601 ± 0.072		2.443 ± 0.072	
Control	5.481 ± 0.271^{a}	0.000***	0.021 ± 0.012^{a}	0.051*	0.691 ± 0.012^{a}	0.025*	2.632 ± 0.071	0.276^{NS}	2.171 ± 0.131	0.864^{NS}
Aqueous extract of the ratio	2,085 ± 0.463^{b}		0.039 ± 0.011^{b}		0.611 ± 0.010^{b}		2.121 ± 0.353		2.012 ± 0.341	
Aqueous extract of the plant	2.862 ± 0.252	0.260^{NS}	0.011 ± 0.011^{a}	0.054*	0.634 ± 0.011	0.185^{NS}	2.601 ± 0.072	0.232^{NS}	2.443 ± 0.072	0.355^{NS}
Aqueous extract of the ratio	2.085 ± 0.463		0.039 ± 0.011^{b}		0.611 ± 0.010		2.121 ± 0.353		2.012 ± 0.341	
Chemical										
control	5.081 ± 0.561^{a}	0.010*	0.091 ± 0.022^{a}	0.021*	0.701 ± 0.011	0.14^{NS}	2.603 ± 0.071	0.818^{NS}	2.154 ± 0.152	0.998^{NS}
Half-dose	2.702 ± 0.471^{b}		0.132 ± 0.013^{b}		0.692 ± 0.012		2.341 ± 0.272		2.171 ± 0.251	
Control	5.081 ± 0.561^{a}	0.000***	0.091 ± 0.022^{a}	0.025*	0.701 ± 0.011^{a}	0.009**	2.603 ± 0.071	0.072^{NS}	2.154 ± 0.152	0.352^{NS}
Dose	1.603 ± 0.541^{b}		0.118 ± 0.011^{b}		0.601 ± 0.011^{b}		1.629 ± 0.441		1.553 ± 0.421	
Half-dose	2.702 ± 0.471	0.321	0.132 ± 0.013	0.115^{NS}	0.692 ± 0.012	0.07^{NS}	2.341 ± 0.272	0.223^{NS}	2.171 ± 0.251	0.322^{NS}
Dose	1.603 ± 0.541		0.118 ± 0.011		0.601 ± 0.011		1.629 ± 0.441		1.553 ± 0.421	

NS – non-significant; * significant at 0.05; ** significant at 0.01; *** significant at 0.001; different letters indicate differences among groups control, aqueous extract of plant *D. viscosa*, aqueous extract of ratio (*D. viscosa/ S. fuscata)*, half-dose and dose of active ingredient; SE – standard error

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Table 3. Estimation of the toxicity of chemical and biological treatments on lipido-carbohydrate energy reserves and weight measurements of *Chaitophorus leucomelas*

Treatments		Energy reserves				Weighable measure	
		Lipid		Carbohydrate			
		Mean ± SE	Wilcoxon test	Mean ± SE	Wilcoxon test	Mean ± SE	Wilcoxon test
Biological	Control	9.041 ± 0.740	0.722^{NS}	0.202 ± 0.014^{a}	0.005^{*}	3.69 ± 0.259^{a}	0.007^{*}
	Aqueous extract of the plant	9.153 ± 1.693		0.166 ± 0.025^{b}		3.245 ± 0.149^{b}	
	Control	9.041 ± 0.740^{a}	0.003^{**}	0.202 ± 0.014	0.878^{Ns}	3.69 ± 0.259^{a}	0.007^{*}
	Aqueous extract of the ratio	12.611 ± 2.896^{b}		0.197 ± 0.035		3.133 ± 0.400^{b}	
	Aqueous extract of the plant	9.153 ± 1.693^{a}	0.003^{**}	0.166 ± 0.025	0.052^{*}	3.245 ± 0.149^{a}	0.005^{*}
	Aqueous extract of the ratio	12.611 ± 2.896^{b}		0.197 ± 0.035		3.133 ± 0.400^{b}	
Chemical	Control	29.783 ± 12.103^{a}	0.041^{*}	0.214 ± 0.029	0.325^{NS}	3.367 ± 0.641	0.413^{NS}
	Half-dose	38.391 ± 2.876^{b}		0.223 ± 0.022		3.289 ± 0.798	
	Control	29.783 ± 12.103^{a}	0.010^{*}	0.214 ± 0.029^{a}	0.046^{*}	3.367 ± 0.641^{a}	0.040^{*}
	Dose	39.688 ± 4.089^{b}		0.240 ± 0.022^{b}		3.779 ± 0.678^{b}	
	Half-dose	38.391 ± 2.876	0.070^{NS}	0.223 ± 0.022	0.063^{NS}	3.289 ± 0.798^{a}	0.040^{*}
	Dose	39.688 ± 4.089		0.240 ± 0.022		3.779 ± 0.678^{b}	

NS – non-significant; * significant at 0.05; ** significant at 0.01; *** significant at 0.001; different letters indicate differences among groups Control, aqueous extract of plant *D. viscosa*, aqueous extract of ratio (*D. viscosa/S. fuscata)*, half-dose and dose of active ingredient; SE – standard error

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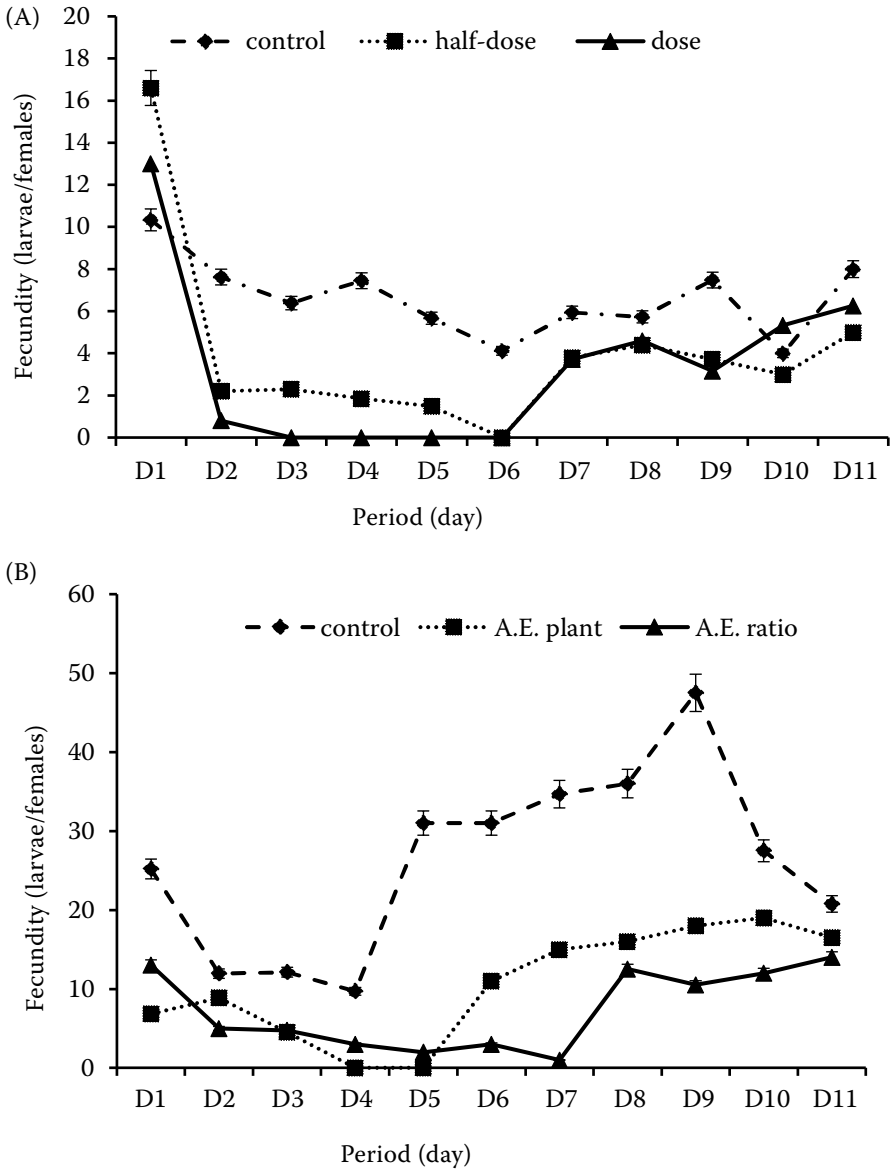

Figure 1. Temporal variation of the fecundity of Chaitophorus leucomelas under the effect of chemical and biological treatments

A.E. plant – Aqueous extract of plant *Dittrichia viscosa*; A.E.ratio – aqueous extract of ratio *Dittrichia/Silene*; half-dose of active ingredient, eose of active ingredient; (A) active ingredient; (B) phytopreparation

ruption of lipid reserves in females exposed to the synthetic product at the specified ratio and doses compared to the control group ($P < 0.01$). However, carbohydrate stores are severely affected by the whole-plant phytopreparation of *D. viscosa* and the homologous dose of the synthetic product ($P < 0.05$). At the same time, weight measurements reveal a significant difference between the two types of treatment ($P < 0.05$).

DISCUSSION

Assessment of the insecticidal potential of phytopreparations and of the active ingredient on the abundance of *Chaitophorus leucomelas.* The results of biological treatments, which included the application of aqueous extracts of the whole plant *D. viscosa*, the aqueous extract ratio of *Dittrichia/Silene*, and the active ingredient, showed a significant knock-down effect on the abundance of *C. leucomelas* sexuparae compared to the control group. The reported shock effect on abundances reveals an increasing gradient of toxicity, from the aqueous extract of the whole plant *D. viscosa*, to the aqueous extract ratio, and finally to the active ingredient.

Considering the results obtained by the cross-correlation test, we find that the aphid populations settle first in the block treated with the aqueous extracts and then in the block treated with the active ingredient. In accordance with these results,

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it can be hypothesised that the synthetic product generates a moderately persistent repressive shock effect on the population of *C. leucomelas*, which is ephemeral under the influence of phytopreparations. Studies have shown that chemicals can disrupt the normal functioning of organisms exposed to them (Jean & Benmarhnia 2011). In other words, the impact of pesticides on harmful organisms targets the integrity of the individual; therefore, a dysfunction of all his biological parameters occurs, where each parameter plays a role in his survival. Very satisfactory results have been found following the use of the aqueous extract of the entire plant *D. viscosa* on the population structure of *C. leucomelas*. These results suggest that the obtained aqueous extracts contain a wide variety of bioactive components released during the extraction process, which act in synergy. This hypothesis is supported by a fairly rich literature which states that *D. viscosa* contains natural defensive substances that have been used as a very diverse therapy and have been known for a long time (Cafarchia et al. 2002; Ouahchia et al. 2020). *D. viscosa* is known for its antihypertensive (Kattouf et al. 2009), anti-inflammatory and antioxidant (Lounis et al. 2009; Kheyar-Kraouche et al. 2018), antidiabetic, antipyretic, wound healing, antiseptic and antiphlogistic activities (Omezzine et al. 2011) and its antiulcerogenic action is attributed to its flavonic composition. Moreover, extracts of *D. viscosa* were tested for their antiviral (Abad et al. 2000), antifungal (Mamoci et al. 2011; Rhimi et al. 2017), antimicrobial (Zouaghi et al. 2021), antibacterial (Squalli et al. 2007; Ounoughi et al. 2020; Mrid et al. 2022), herbicidal (Muehlchen et al. 1990), nematicidal (Oka et al. 2006), acaricidal (Mansour et al. 2004) and insecticidal activities (Alexenizer & Dorn 2007; Belhamra et al. 2024). The aqueous extract ratio expressed a remarkable toxic action compared to the unformulated aqueous extracts. The use of ratios increased the insecticidal efficacy of *D. viscosa* and reduced the incidence of side effects on population recovery. Presuming that the bio-adjuvant *S. fuscata* accelerates the penetration of the bioactive molecule, this implies that the distribution of the biomolecules to the sensitive sites of the pest occurs in a relatively short period of time. These results are consistent with the results of other researchers such as Hayes et al. (2006), who also showed that the adjuvant is used primarily to increase the quantity and penetration speed of the product into organisms, therefore to increase its speed of action, to expand its functions and to offer it a better adhesion. According to Hernandez Ochoa (2005), bio-adjuvants enhance the performance of active ingredients by significantly reducing the usable doses, thereby limiting their impact on flora and fauna and helping to protect the environment.

Evaluation of the insecticidal potential of *Dittrichia viscosa* aqueous extract-based phytopreparations on the demographic parameters. The results relating to the application of the different treatments on *C. leucomelas* allowed us to clearly see that fecundity is remarkably disturbed following the action of the active ingredient compared to aqueous extracts. These results are comparable to those discussed by Bernard (1992), who explained that most pesticides act on the fecundity of contaminated organisms by causing partial or total sterilisation and by reducing the number of eggs laid. Dallaire (2003) demonstrates that tebufenozide impacts the development, as well as certain aspects of chemical communication and reproductive success, in insects such as Lepidoptera. This product causes a deceleration in ovarian maturation, resulting in a decrease in the fecundity of females. Additionally, the effects of tebufenozide on fecundity and fertility were found to vary significantly depending on the stage of development at the time of treatment. In the same aspect, bioproducts have insecticidal and anti-appetising effects, thus affecting the growth, moulting, development and fecundity of insects (Konstantopoulou et al. 1992; Keane & Ryan 1999). The net reproductive rate of *C. leucomelas* females exposed to phytopreparations and to Thiamethoxam/Lambda-cyhalothrin underwent a notable decline compared to the control. This decline is particularly pronounced under the homologous dose of the active ingredient Thiamethoxam/Lambda-cyhalothrin compared to the aqueous extracts applied. Regarding the growth rate of *C. leucomelas* cohorts, the results demonstrate a significant increase in growth between the treated and control groups. This increase is much pronounced following the action of the active ingredient compared to that of the aqueous extracts. The results show that the prescribed dose of the active ingredient and the aqueous extract of *D. viscosa*/*S. fuscata* ratio cause a significant decrease in the multiplication rate of the populations studied. A significant decrease in the mean lifetime is reported in the population of *C. leucomelas* following the use

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of the homologous dose of the active ingredient, compared to other treatments that remain close to the control. Ultimately, the various treatment systems have a minimal impact on the doubling time of the populations. The toxic effects of pesticides on demographic parameters are scarce in the scientific literature.

Evaluation of the insecticidal potential of phytopreparations and of the active ingredient on the biochemical life traits of *Chaitophorus leucomelas*. Studies show that chemicals can reach all the intracellular organelles and change their number, structure and location in the cell and that they can also act on intracellular energy reserves (lipids and glycogen) (Gernhöfer et al. 2001; Triebskorn et al. 2002). Calow (1991) proves that energy reserves are mobilised following stress. This investigation aims to elucidate the role of energy biomarkers in understanding the behavioural or physiological strategies that enable *C. leucomelas* females to partially or completely circumvent bioactive or active materials. This study describes the metabolic reactions and weight measurements of *C. leucomelas* under the effect of phytopreparations and the synthetic product. The results reveal a significant quantitative change between lipid and carbohydrate reserves stored in the tissues of biological model females, where lipid reserves are clearly distinguished from carbohydrate reserves. Moreover, it is crucial to coordinate the strong positive correlations between the reorganisation of lipid reserves and the chemical treatment under different applied doses. The dominance of energetic lipid biomarkers can likely be attributed to changes in the biochemical life traits of females exposed to different applications, particularly the active ingredient. This hypothesis can be explained by the fact that the synthetic product has a stimulating effect on the physiology or the behaviour of an organism after exposure. The weight measurements show a slight disturbance under the effect of the two treatment types compared to the control. Several authors point out that exposure to chemical stress can disrupt the energy balance of living organisms as a direct consequence of the tolerance means adopted (e.g. defence mechanisms, damage repair) and this at the expense of the energy allocated to reproduction and to growth (Amiard & Amiard-Triquet 2008; Palais et al. 2011). This energy balance can also be negative under certain environmental conditions, resulting in the consumption of energy reserves to activate and/or establish tolerance and defence mechanisms. Our results are consistent with those of other studies, which show that organisms exposed to chemical contamination use energy to mitigate the physiological alterations caused by substances present in the environment. Thus, the amount of energy available to ensure the body's vital functions will be lower than that in unexposed organisms. The dosage of energy reserves (proteins, glycogen and lipids) allocated to the various functions of the body will then provide information on the overall physiological state of living organisms (Poisson et al. 2011). The results demonstrate a strong accumulation of lipid reserves in the cohort exposed to the synthetic product. This lipid accumulation indicates that the treated females are, in fact, subjected to a stressful action that could stimulate high production and greater accumulation of lipids. The explanation most often described in the literature is that lipids generally accumulate in organisms exposed to organic contaminants (Köhler 1989; Pelosse 2008). Hence, an increase in lipid metabolites promotes the storage of the toxic substance. According to Abdoulaye (2007), lipids are necessary for maintaining good health, as they contribute to the formation of cell membranes and the synthesis of hormones. Additionally, they represent a concentrated source of energy that is twice as much as carbohydrates or proteins. The lipid content is closely related to survival, suggesting that a decrease in lipid stores may be responsible for the death of individuals. However, it should be noted that the measured lipid level corresponds to the amount of lipids contained in the entire body of the insect. Lipids play various roles in insects, which may contribute to their survival, dispersal, or even serve as a crucial source of energy for egg production (Pelosse 2008). The results indicate a relatively significant disturbance of the carbohydrate energy balance in *C. leucomelas* females after administering the dose of the active ingredient. Carbohydrate biomarkers are very low but stable, which suggests that the low amount of sugar is related to the detoxification action. Finally, many stresses (physical and/or chemical) can lead to the mobilisation of energy reserves. In addition to variations related to exposure to toxicants, the variability of the energy reserve concentrations in organisms depends on several biotic and/or abiotic factors. These energy reserves can be mobilised to supply defence mech-

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anisms (storage, elimination, detoxification of contaminants). In this toxic situation, energy reserves can provide vital information on the maintenance, growth and reproduction capacities of individuals (Amiard & Amiard-Triquet 2008).

CONCLUSION

This study was conducted to evaluate the efficacy of aqueous extracts against the black poplar leaf aphid, *C. leucomelas*. The use of the *D. viscosa*/*S. fuscata* aqueous extract ratio enhanced the toxic potential of bioactive compounds, as demonstrated by significant aphid mortality and a satisfactory duration of phytosanitary coverage compared to the aqueous extract of whole *D. viscosa*. The results show that synthetic pesticides have a significant disruptive effect on the lipid-carbohydrate reserves of exposed populations compared to phytopreparations. The temporal assessment of fecundity is shown to be remarkably disturbed after applying the synthetic pesticide compared to the aqueous extract. A slight disturbance was recorded in the growth rate of the populations exposed to the two treatments compared to the control group. Futhermore, the female's reproduction rate is influenced by both treatments, with a stimulating disturbance of the active ingredient compared to the phytopreparations. Likewise, the prescribed dose of the active ingredient generates a considerable average disturbance on the multiplication rate and the average generation time of the studied populations compared to the other products used. The results also show that the different treatments applied do not affect the doubling time of *C. leucomelas. D. viscosa*/*S. fuscata* extracts may be a highly promising potential source of bioactive molecules against insects.

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