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PhytochemicalCharacterisationandInsecticidalPotentialofErica arboreaL. Extracts AgainstSitophilus granarius(L.): Towards an Eco-Friendly Pest Management Approach

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Abstract
Thisstudyassessesthephytochemicalcompositionandinsecticidalactivityofaqueous and ethan olic extract sobtained from Eri caarb oreal eaves collected in western Algeria. Extraction yields, total phenolic content, and insecticidal efficacy against Sitophilus granaries were determined.
The higher yield were obtained with thanoli cmaceration(22.18%inOran;20.18%in Saïda), whereas the lowest were recorded with Soxhlet extraction using hexane (~4– 4.5%). The ethanolic extract sex habited a maximum mortality rate of 69%at32µl·ml⁻¹ after 72 hours. These findings confirm the potential ofErica arborea,as a natural source of bio-pesticidal compounds suitable for sustainable pest control
Keywords: *Ericaarborea, plantextracts, phenoliccompounds, Sitophilusgranarius, biopesticide,Algeria.*

1. INTRODUCTION

The excessive and uncontrolled use of synthetic pesticides in modern agricultural systems, has for several decades, led to serious ecotoxicological and public-health consequences. These chemical substances persist in the environment, accumulate in food chains, and disrupt natural ecological balances. Moreover, many insect pest species have developed increasing resistance to these molecules, which considerably reduces their long-term effectiveness (Mann, 1987).
In this context, the search for ecological and sustainable alternatives to chemical insecticides has become a major priority for crop protection and humanhealth preservation. Aromatic and medicinal plants, owing to their second arymetabolitessuch as polyphenols, flavonoids, terpenoids, and alkaloids, represent a promising source of bioactive substances with biopesticidal potential. These natural compounds exhibit a wide range of biological effects—antioxidant, antibacterial, antifungal, and insecticidal—often with high biodegradability and low toxicity towards non-target organisms. Accordingly, the present study is part of a broader approach to valorise Algerian plant resources through the evaluation of the insecticidal potential ofErica arboreaextracts collected from two regions of western Algeria (Oran and Saïda). Specifically, it aims to:

- Compare extraction yields using different techniques (maceration, ultrasound,Soxhlet).
- Quantify total phenolic compound sinthe extracts.
- Evaluate the in secticidal activity of these extract sa gainst S.granarius.

Thisstudythereforecontributestoabetterunderstandingofthebiopesticidalpotential ofErica arboreaand promotes an integrated pest management approach that is environmentally friendly and adapted to local agroecological conditions.

2. MATERIALS AND METHODS

2.1. Study Species and BiologicalModel

Erica arboreaL., commonly known as “tree heath”, occupies a special place within Mediterranean forest ecosystems. This woody species, belonging to the Ericaceae family, is widely distributed across the Mediterranean Basin, particularly in North Africa, southern Europe ,and some Atlanticregions .In Algeria it grow smainlyinthe mountain ousareas of the Northand West, wherei contribute stosoilstability erosion control, and the regeneration of degraded maquis formations (Aït Youcef, 2006).
Sitophilusgr anarius (L.), commonly known the granary weevil, is one of the major pests o stored grains

worldwide. It causes severe economic losses in both quantity and quality by damaging cerea stock and reducing their nutritional value. The use of ynthetic chemicals to control this pest often results in food contamination and environmental pollution, highlighting the importance of testing local plant extracts as alternative solutions.

2.2. Study Area

Sample of Erica arboreaL. Were collected from two representative regions of western Algeria: **Saïda** and **Oran**, characterised by contrasting bioclimatic conditions.

- **Saïda Region:**

Located at 34°50' N and 0°10' E, Saïda lies within a semi-arid bioclimatic stage with cold winters. Annual rain fall ranges between 300and450mm,with an average temperature of approximately 16 °C. The vegetation is mainly composed of maquis dominated by holm oak (Quercus ilex), Aleppo pine (Pinus halepensis), and heaths (Erica arborea,E. multiflora).

- **Oran Region:**

Situated at 35°42' N and -0°38' E, Oran experiences a milder Mediterranean climate with higher humidity. Average annual rain fall variesbetween450and 600 mm, and mean annual temperature is around 18 °C. The substrate is primarily calcareous, and the natural vegetation consists of typical coastal maquis formations with shrubby and herbaceous species.

2.3. Preparation of Plant Material

Leave ofE. arboreawere collected from healthy plants identified in the field during the flowering period (March–April 2024). Samples were placed in paper bags and transported to the laboratory for drying and processing.

The leaves were carefully washed with distilled water to remove impurities, then air- dried in the shade at ambient temperature (20–25 °C) for 10 days (Salah Dine&al., 2019).Once completely dry, the plant material was ground using an electric grinder to obtaina fine, homogeneous powder, which from light and moisture until extraction.

2.4. Extraction Techniques

Four extraction method swere compared to assess their efficiency:

1. **Ethanolic Maceration(MAE):**

Twentygramsofpowderedleaveswereimmersedin200mlof80%ethanol for 72 hours with intermittent manual stirring. The filtrate was then concentrated under reduced pressure at 40 °C using a rotary evaporator.

2. **Ethanolic Ultra sonic Extraction(UE):**

Twentygramsofpowderedmaterialweremixedwith200mlof80%ethanol and subjected to sonication (40 kHz) for 30 minutes at room temperature (Zengin &al., 2019).

3. **Aqueous Ultra sonic Extraction(UA):**

The same protocol was applied asi the UE method, butd is tilled water was used as solvent (Zengin&al., 2019, modified).

4. **Soxhlet Hexane Extraction(SOH):**

Twenty grams of powdered leaves were extract dusing200mlofhexanefor 6 hours in a Soxhlet apparatus (Zengin &al., 2019).

The obtained extract were filtered, concentrated, andair- driedat room temperature. Extraction yields were calculated according to the following formula:

$$R(\%) = \frac{M(ext)\times 100}{M(éch)}$$

- M Text=mass of the xtract after solven te vaporation (g)
- M sample=mass of the plant material used (g)(Benyamina,2019)

2.5. Determination of Phenolic Compounds

2.5.1. Total Polyphenols

ThetotalpolyphenolcontentwasdeterminedusingtheFolin–Ciocalteumethod.A stock solution(1 mg/ml)of each extract was prepared. Then, 0.1 ml ofthis solution was mixed with 0.5 ml of Folin–Ciocalteu reagent and 1.5 ml of 7.5% Na_2CO_3. After incubation for 30minutesat 25°C, absorbanc was measuredat765nmusingaUV-Visspectro photo meter (UV-Vis1800,Shimadzu) (Feknous&al.,2014). Results were express eda smillig rams of gallic acid equivalent sper gram of dry extract (mg GAE/g).

2.5.2. Total Flavonoids

Thequantitativeestimationoftotalflavonoidsintheleafextractswasperformed using a colorimetric method. Two millilitres of ethanolic $AlCl_3$ solution (2%)were addedto 2mlofeachextract. After a 10-minute incubation period, absorbance was measured at 430 nm (Guendouze- Bouchefa&al., 2015).

The concentration of flavonoids was calculated using a calibration curve established withquercetin,andresultswereexpressedasmgQE/gofextract(Heinrich&al.,2017).

2.5.3. Condensed Tannins

Onemillilitreofeachextractwasaddedto2mlof1%vanillinsolutionandthoroughly mixed. The mixture was left to react at room temperature for 20 minutes, after which theabsorbancewasreadat500nmagainstablank. The concentration of condensed tannins was determined using a catechol calibration curve, and results were expressed as mg CE/g of extract (Benyamina, 2019).

2.6. Insecticidal Bioassays

2.6.1. Target Insect

Adults fSitophilus granarius(L.) were obtained from a laboratory culture reared on durum wheat (Triticum durum). The insects used in the experiments were 7–14 days old.

2.6.2. Contact Toxicityon Filter Paper

The in secticidalactivityoftheplantextractswasevaluatedusingthefilterpapercontacttest (Seri-Kouassi & al., 2004). Groupsoftenadultweevilswereplacedin Petridishescontainingwheatgrainstreated with differen text ract concentrations(8,16,24,and32µl/ml).

Mortality observations were madeafter24, 48, and 72 hours(SalahDine et al., 2019). Untreated controls were included for each series, and all tests were conducted intriplicate.

2.6.3. MortalityRate

Mortality was the primary criterion for assessing the effectiveness of the treatments. The observed mortality percentage in both control and treated groups was calculated using the formula described by Ould El Hadj&al. (2006):

$$\text{Observedmortality} = \frac{\text{Numberofdeaths}}{\text{Totalnumberofindividuals}} \times 100$$

2.6.3.1. Calculation of the Mortality Rate

The mortality rate was calculated according to Abbott's formula(1925):

$$MC(\%) = \frac{(M2-M1)}{(100-M1)} \times 100$$

where:

- MC=correctedmortality(%)M2=mortalityinthetreatedpopulation(%)M1=mortalityinthecontrol population (%)

Thiscorrectionensuresthattheeffectofnaturalmortalityorhandlingstressinthe control batches is excluded from the final analysis of insecticidal activity.

2.7. Sttistical Analysis

Data were analyse dusing **SPSS software(version22.0)**. A**one-way analysis of variance(ANOVA)**wasused to compare means, followed by**Tukey'sHSDtest** to determine significant differences($p<0.05$). Pearson's correlation coefficients were calculated to evaluate relationships between concentration, exposure time, and mortality rate, thus assessing the dose–response relationship.'

3. RESULTS AND DISCUSSION

3.1. General Appearance and Colour of Extracts

The extracts obtained from Erica arborea leaves exhibited **distinct physical characteristics** depending on the extraction method and solvent used. (table N1)

Table1.Physical appearance and colour of the four extract s obtained from Erica boreal eaves

Extraction Method

Appearance	Colour	Colour	Appearance
(Oran)	**(Saïda)**	**Oran)**	**(Saïda)**
Bottlegreen	Lightgreen	Powdery	Powdery
Bottlegreen	Lightgreen	Pastelike	Pastelike
Brightbrown	Brightbrown	Powdery	Shiny
green	green	Mattpowder	Mattpowder

Ethanolic maceration (MAE)
Ethanoli cultra sound (UE) Aqueous ultrasound (UA)Hexane Soxhlet (SOH)
The variation in colour and texture between extracts reflects the**influence of solvent polarity**on the chemical profile of the extracts. Ethanol-based extracts are richer in oxidised phenolic compounds (hence darker tones), while aqueous extracts appear clearer due to hydrosoluble tannins. Hexane extracts are pale and oily, dominated by lipidic or terpenoid compounds.
ThesefindingsareconsistentwithpreviousobservationsreportedbyYaici&al.(2019) forE. arboreaand by Bessah & Benyoussef (2014) for other Mediterranean aromatic plants.

3.2. Extraction Yields

Extraction yields varied between**4.05% and 22.18%**, depending on the extraction technique and the plant's geographical origin (Table 2, Figure N1 and Figure N2)

Table2.ExtractionyieldsofdifferentEricaarborealeafextracts

Mass (g) – Oran	– (g) Mass Saïda	– (%) Yield Oran	– (%) Yield Saïda
1.109	1.009	22.18	20.18
1.65	1.01	16.50	10.10
1.09	1.11	10.00	11.10
0.909	0.81	4.55	4.05

Extraction Method
Ethanolic maceration (MAE)
Ethanolic ultrasound (UE)Aqueous ultrasound (UA)Hexane Soxhlet (SOH)

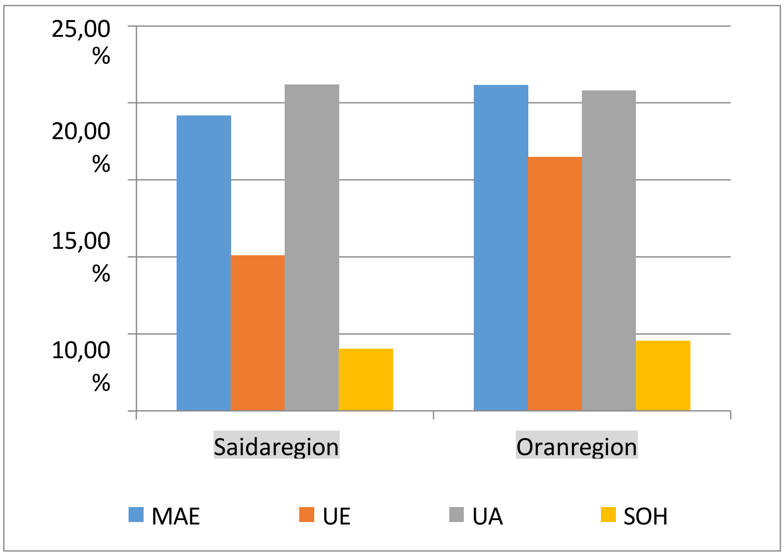

Figure1. ExtractionyieldsofEricaarborealeafextractsaccordingtogeographicalorigin(SaïdaandOran)

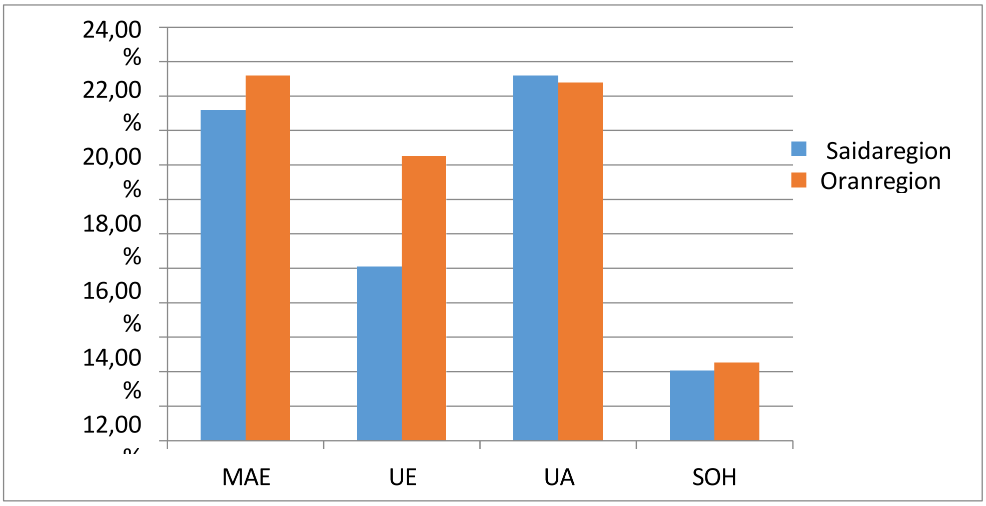

Figure2. Comparison of extract ion yields according to extract on method (MAE,UE,UA,SOH).

The **ethanolic maceration (MAE)**method produced the highe yields, followed by **ethanolic ultrasonic extraction (UE)**.This can be attributed to the intermediate polarity of ethanol, which is capable of extracting both polar and slightly non-polar metabolites, such as polyphenols andf lavonoids. Aqueou sex traction (UA) producedin termediate yields, while Soxhle text raction using hexane (SOH) gave the lowest results, as this non-polar solvent primarily dissolves lipids and waxes.
Comparatively, Yaici&al. (2019), working on aqueous extracts ofE. arborealeaves from the Sétif region, reported similar though slightly lower yields (14.74%). Amroun & al.(2021), who studied ethanolic and aqueous sex tracts from the Tizi Ouzou region, obtained comparable values (17.17% for aqueous and 16.63% for ethanolic extractions), confirming the influence of both method and origin on extraction efficiency.

3.3. Quantitative Analysis of Phytochemicals

3.3.1. Total Phenolic Content

From the calibration curve constructed with gallic acid (Figure3),

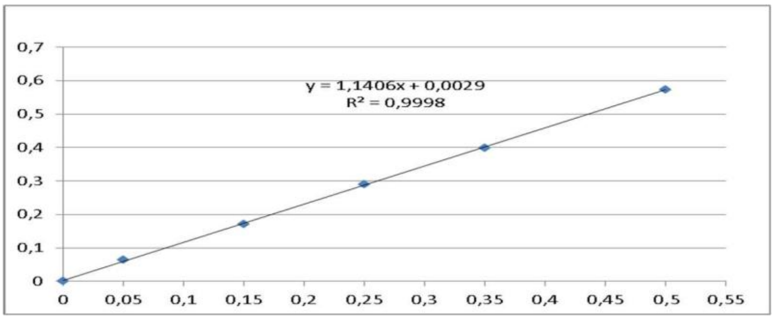

Figure 3. Calibration curve used for the determination of total phenolic compounds (gallic acidstandard).

totalphenoliccontentrangedfrom**60.66±1.21to5.5±0.24mgGAE/gdryextract**in Saïda samples, and from**51.7 to 13.9 mg GAE/g**in Oran samples.
ThehighestconcentrationwasrecordedinSaïdausing**aqueousultrasonicextraction (60.66 mg GAE/g)**, while the lowest was obtained using**hexane Soxhlet extraction(5.5mgGAE/g)**.
Among all methods, **ethanolic maceration** and **aqueous ultrasound** produced the richest extracts in both regions (52.95 ± 2.32 mg GAE/g in Saïda and 51.7 ± 1.95 mg GAE/g in Oran).(Figure N4 and Figure N5)

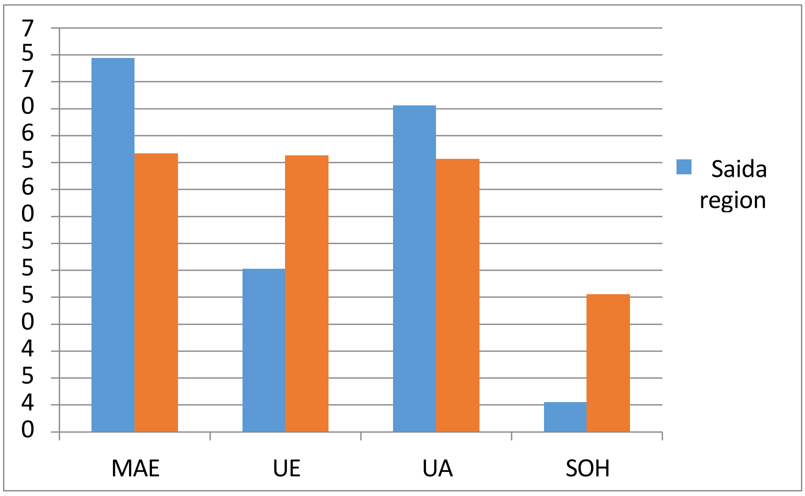

Figure4. ComparisonoftotalpolyphenolconcentrationsindifferentEricaarborealeafextracts.

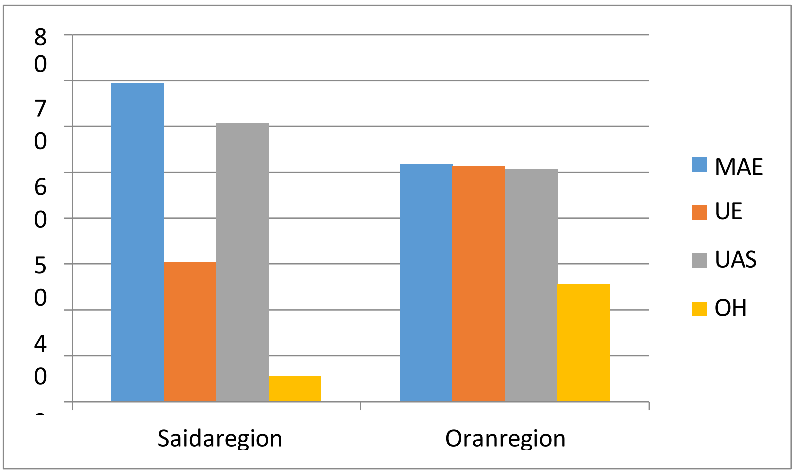

Figure5. Comparisonoftotalphenoliccontentsbetweenthetwostudysites(SaïdaandOran).

These differences indicate that extraction efficiency strongly depends on solvent polarity and technique. When compared with other Algerian studies, our results are slightly lower than those reported by Yaici&al. (2019) in Sétif (74 mg GAE/g), Guendouze&al. (2015) in Béjaïa (70.8 mg GAE/g), Am roun&al. (2021) in Tizi Ouzou (139 mg GAE/g), and Belarbi&al. (2018) in Tlemcen (168.23 mgGAE/g).Globally, however, these value remain within the range observed for Mediterranean E. arborea populations. For example, reported**75.83 mg GAE/g**in Turkish samples by Ay&al.,(2007) and **78.49mg GAE/g**inTurkish sample Amezouar & al.,(2013).

3.3.2. Total Flavonoids

Using a calibration curve stablished with quercitrin (Figure6), total flavonoid content varied between **17.86mgQE** /gand**10.9mgQE**/ginSaïda, andfrom**9.62mg QE**/gto**24.81 mg QE**/gin Oran. the results are presented in figure 7.

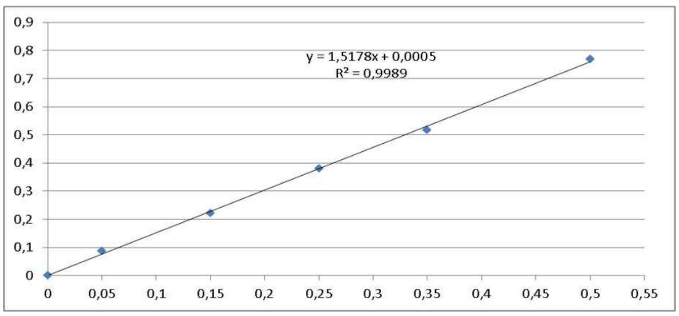

Figure6. Calibration curve used for the quantification of total flavonoids (quercitrin standard).

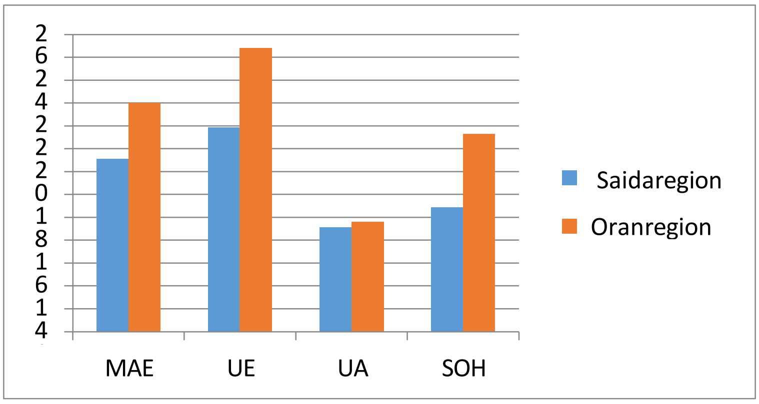

Figure7. Comparison of total flavonoidc once ntrationsin the different Ericaar boreale fextracts
The **ethanolic ultrasonic extraction (UE)**method yielded the richest flavonoid contents for both regions, followed by maceration. In general,t he Oran extract sc ontained slightl yhigher flavonoid level sthan those from Saïda, possibly reflecting local climatic and soil influences.

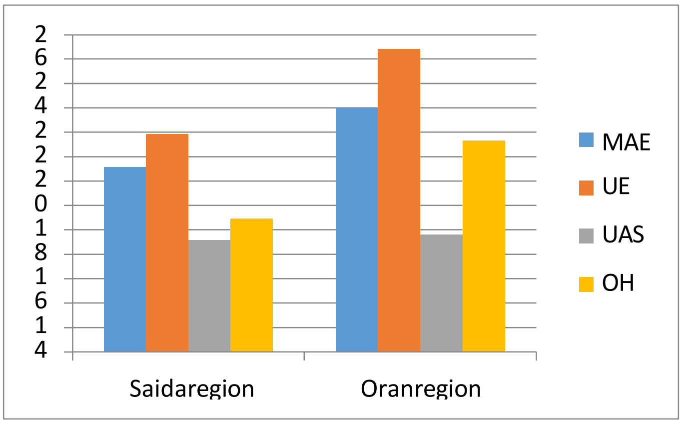

Figure8. ComparisonoftotalflavonoidcontentsbetweenSaïdaandOransamples.

3.3.3. Condensed Tannins

Based on the catech in calibration curve (Figure9),

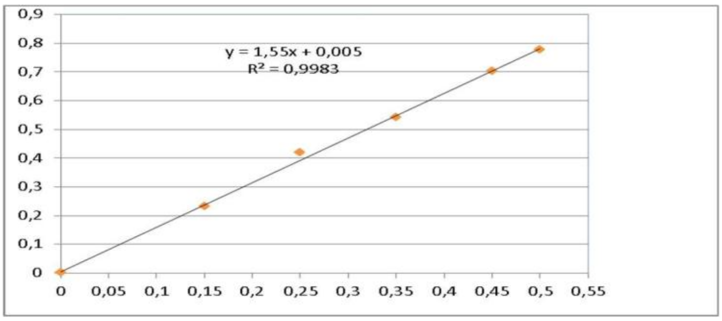

Figure9. Calibrationcurveusedforthedeterminationofcondensedtannins(catechinstandard).
The tannin content was relatively low across all extraction methods and study sites, ranging from**5.17 to7.96 mg CE/g extract**. This variation may be related to environmental conditions, collection period, genetic factors, and extraction parameters. (Figure 10 and 11).

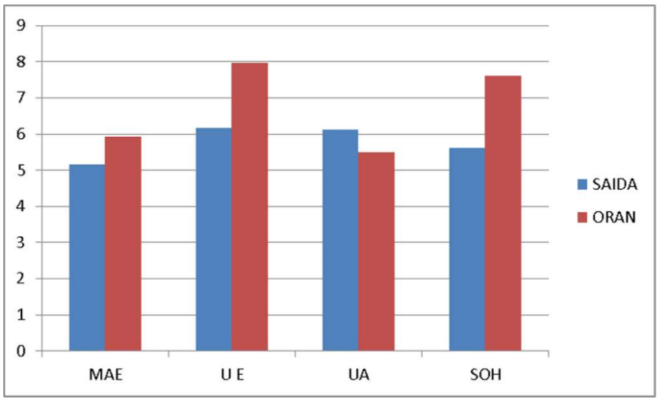

Figure10. Comparison of condensed tannin concentration sinthe different E. arborealeaf extracts.

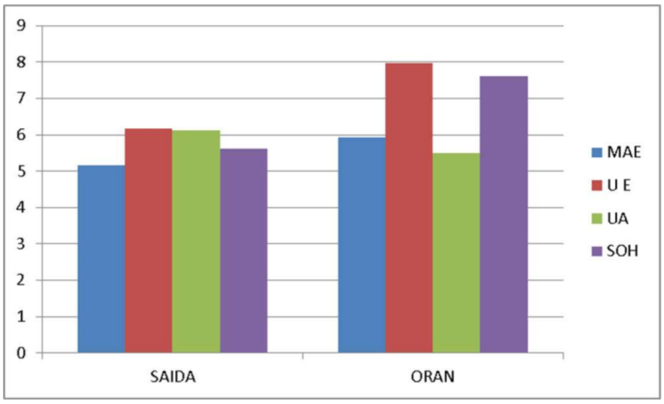

Figure11. ComparisonofcondensedtannincontentsbetweenSaïdaandOranregions.

According to Richter (1993), the content and chemical composition of secondary meta bolite scanvary widely due to both on trinsic (genetic) and extrinsic (environmental and methodological) factors.

3.4. Insecticidal Activity of Ericaar borea

3.4.1. Mortality Rate and Dose–Response Relationship

Because some mortality occurredin control groups, Abbott's (1925) formula was used to correct mortality data. The mortality rates of S. granariu adults exposed to different concentrations of arborea extracts are shown in Figure 12. A clear variation was observed among treatments depending on extract type, concentration, and exposure duration. The **ethanolic maceration extract** produced the **highest corrected mortality (69%)**at32µl/mlafter72hours.

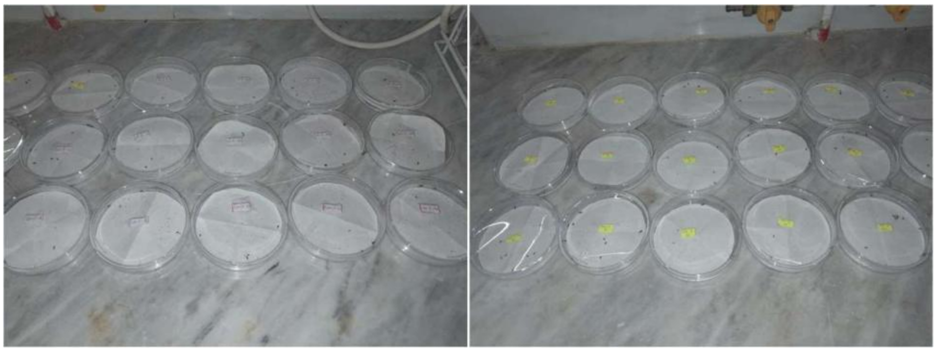

Figure12. PhotographicrepresentationshowingtheeffectsofdifferentconcentrationsofE. arborea leaf extracts on Sitophilus granarius adults.

As shown in Figures 13 and 14, mortality increased linearly with both concentration and exposure time, indicating **dose- dependent toxic effect** of E.arborea extracts on S. granarius.

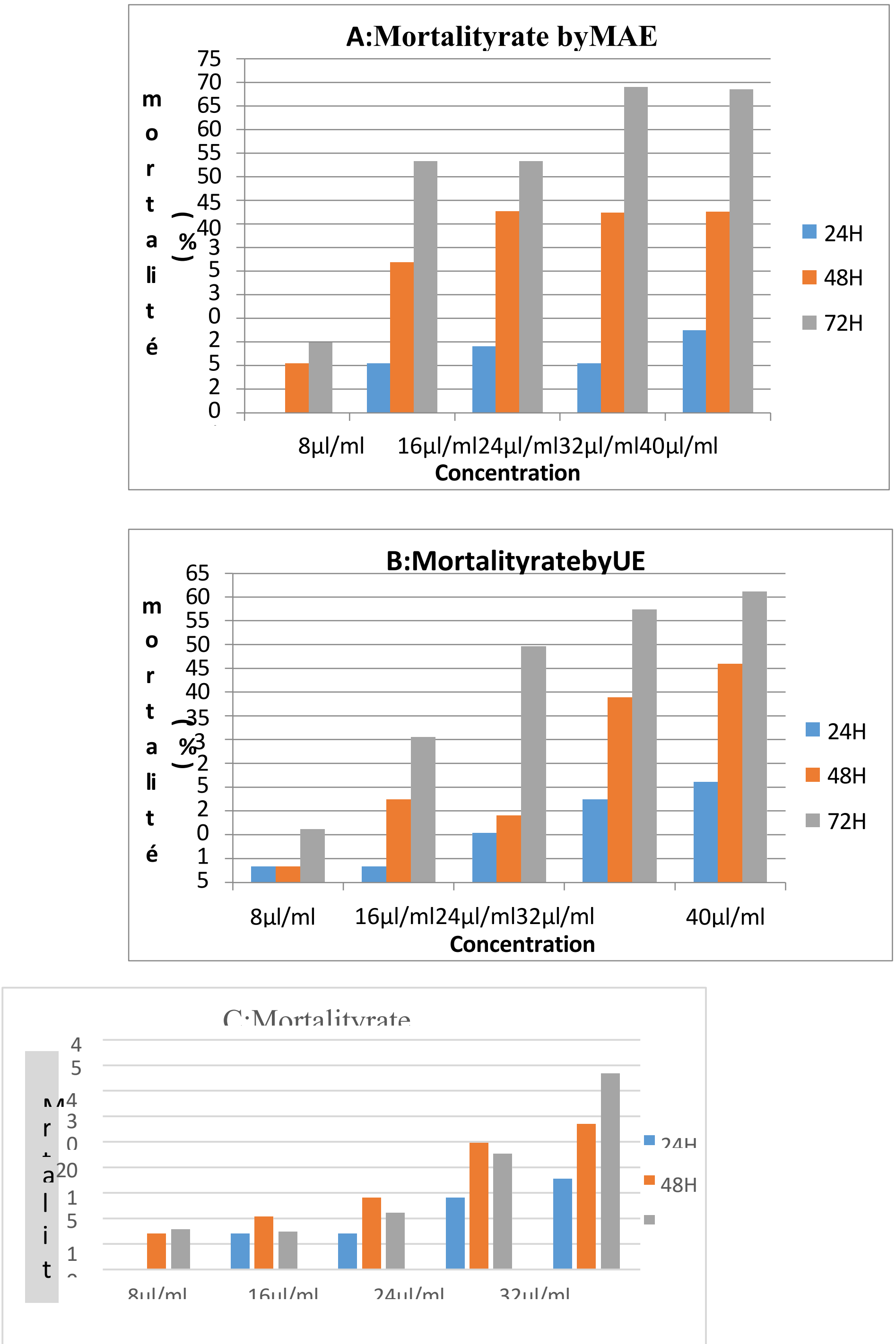

Figure13. (A,B,C): Mortality rates of Sitophil us granarius adults exposed to various E .arborealeaf extracts.

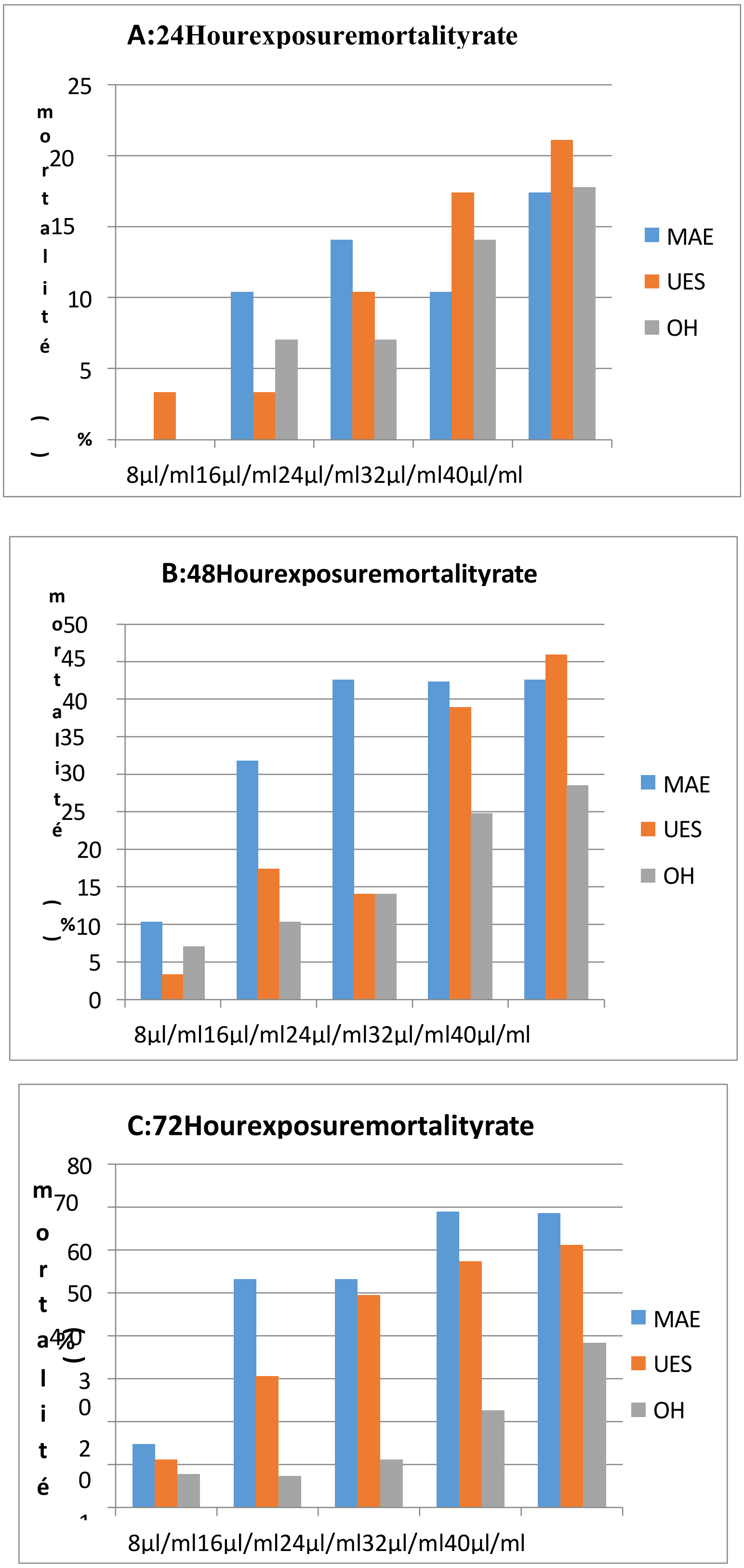

Figure14. (A,B,C): Time-course variation in the mortality rate of Sitophil us granaries after exposure to E. arborea leaf extracts.

4. GENERAL DISCUSSION

The overall result obtained in this study highlight both the **chemical richness** and the **biological potential** of Erica arborea extracts collected from the Saïda and Oranregions in western Algeria. Although often regard edasase condary species in Medite ranean for esteco systems, E. arborea demonstrates here a**significant ecological and biotechnological value**.

The **differences in extraction yield**observed among the various methods reflect the diversity of chemical compounds present in the plant and their variable affinities for the solvents used. Ethanolic extracts proved to be the most effective, both in terms of yield and total phenolic content, confirming that **polar solvents**promote the extraction of phenolicand flavonoid metabolites .These results are consistent with the findings of Guendouze et al. (2015) and Yaici et al. (2019), who reported a strong correlation between solvent polarity and the concentration of phenolic compounds in Ericaceae species.From a biological perspective, the**insecticidal activity** observed agains Sitophilus granaries was significant and dependent on both concentration and exposu reduration. The maximum mortality rate (69%after72hoursat32µl/ml) demonstrates the **progressive toxicity** of E. Arboreaethanolic extracts.This effect is likely due to the **combined action**of polyphenols, tannins, and flavonoids, which are known to damage cellular membranes, in hibitdi gestiveen zymes, and disrupt the energy metabolism of insects Similar mechanism shave been reported by Bessah and Ben yous self(2014) in Rosmarinus officinal is and Thymus vulgaris, two Mediterranean aromatic species also rich in phenolic metabolites.

The **geographical variations** observed between the Saïda and Oran samples could be linked to**local ecological factors**such as soil type, humidity, light intensity, and temperature, all of which influence the bio synthesis of secondary metabolites. Such **eco-chemical variation s**are commonly observed in aromatic and medicinal plants, where environmental condition play akeyrole in both the quality and quantity of bioactive compounds produced (Aït Youcef, 2006).

From an applied perspective, the results of this study open the way forth e**valorisation of Ericaarborea** as a potential source of **natural bio pesticides**. The use of plant-based extracts could help reduce dependence on synthetic agrochemicals, protect the environment, and contribute to the preservation of local biodiversity.

Furthermore, this approach is fully consistent with the objectives of **sustainable development and agroecology**, promoting the rational use of native plant resources.

Itshouldalsobenotedthatthe**chemicalcompositionofE.arboreaextracts**mayvary depending on the season, the plant part used, and the extraction conditions. Further chromatographic analyses (e.g. HPLC, GC–MS) are required to **identify and quantify** the active molecules responsible forth in secticidal effect. Future research should also assess the **toxicity of these extracts on non-target organisms** to ensure their environmental safety before any practical application.

5. CONCLUSION

The study conducted on Erica arboreaL. demonstrated its**high phytochemical richness** and **promising insecticidal potential** against Sitophilus granarius, a major pest of stored cereals.

Extraction yields and total phenolic contents varied depending on both the extraction method and the geographical origin of the samples, with**ethanolic and aqueous extracts obtained by maceration and ultrasonic techniques**showing the highestconcentrations of bioactive compounds. These findings confirm that**solvent polarity**plays a key role in the extraction efficiency of secondary metabolites. The bioassays revealed a**significant dose–response relationship**, with a**maximum mortalityrateof69%** observed at 32µl/mlafter72hoursofexposure.This insecticidal efficacy, mainly attributed to the presence of **polyphenols and flavonoids**, highlights the protective role of these natural compounds against grainpests.

The variability observed between samples from Saïda and Ora nunder lines the **influence of ecological and bioclimatic conditions** on the chemical composition and biological activity o plant extracts. Therefore, Erica arboreare presents a**valuable local plant resource** that could be exploited for the development of **eco-friendly biopesticides** adapted to the agroecological systems of north-western Algeria.In conclusion, Erica arborea can be considered a**species with high biotechnological potential**, capable of contributing to the transition to ward sa **greener, safer, and more sustainable agriculture**.

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