Botanicals: A Path to Greener Pest Control?

Marie-Laure Fauconnier, Manon Genva and Clément Burgeon

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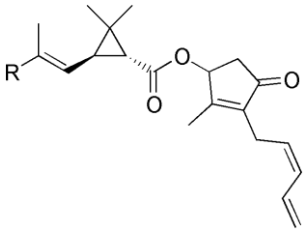
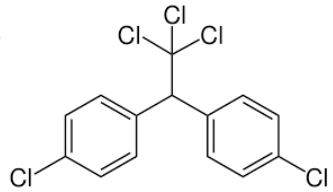
Botanicals: what's that?

Common definition:

> *Substance obtained from a plant and used typically in medicinal or cosmetic products.*

➔ Also in the field of crop protection





- Not new …before 1940: very common (tobacco extract, rotenone, pyrethrum …)
- 1940-2000 DDT and many chemically synthetized pesticides: botanical pesticide research slows down
- 2000: resistance, environmental and human health concerns ➔ research on botanicals coming back into fashion

Botanicals: what's that?




For the agronomist, botanicals are

- Herbicide
- Insecticide
- Fungicide
- Nematicide
- Molluscicide
- Rodenticide
- Virucide
- Acaricide
- Bactericide

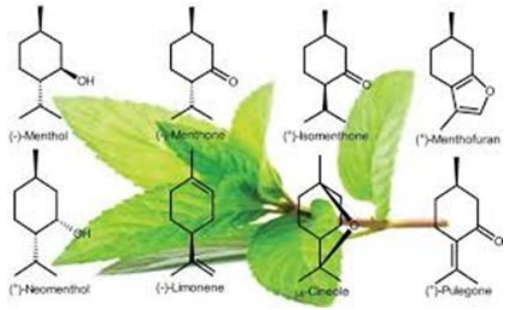
Biocides

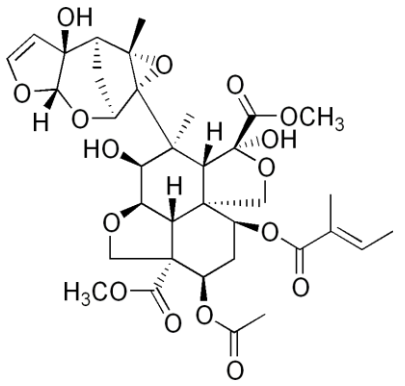
- Anti-sprouting agent
- Soil quality improvement agent

Key words in *Google Scholar*: essential oils and …

- Insecticide (GS 125000)
- Herbicide (GS 69000)
- Bactericide-fungicide (GS 91000)
- Acaricide-nematicide (GS 37500)

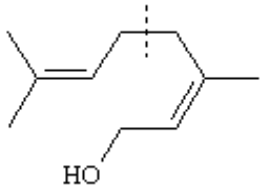
Botanicals: what's that?

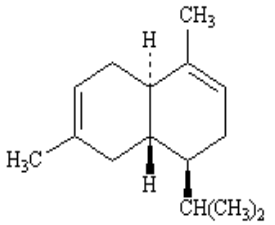


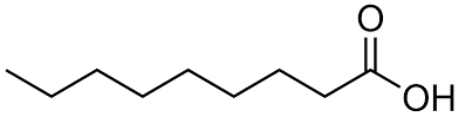


For the chemist:

- A pure compound or purified fraction requiring an extraction method and one/several purification steps (*e.g.* azadyractin from neem oil)
- A complex extract requiring an extraction method (solvent, SC-CO_2, hydrodistillation, steam distillation, *e.g.* essential oils)
- An analog of botanical obtained by synthesis/biosynthesis from biosourced (or not) reagents (pelargonic acid)
- Volatile / non-volatile compounds; apolar or polar compounds
- Compounds belonging to various chemical functions (terpenoids, acids, alcohols, ketones, esters, S and N containing compounds, phenolics, ...)







Botanicals: focus on essential oils, an emerging class of botanicals

Definition of EOs

Essential oils are complex mixtures of volatile compounds produced by living organisms and isolated by physical means only (pressing and distillation) from a whole plant or a plant part of known taxonomic origin.

➔ A plant extract obtained by solvent extraction (like vanilla) or by supercritical CO_2 is NOT an essential oil !

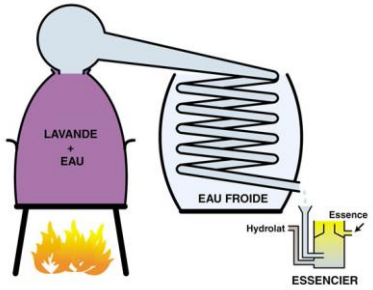
➔ Essential oils are NOT oils (like peanut oils)

Can all plants produce essential oils?

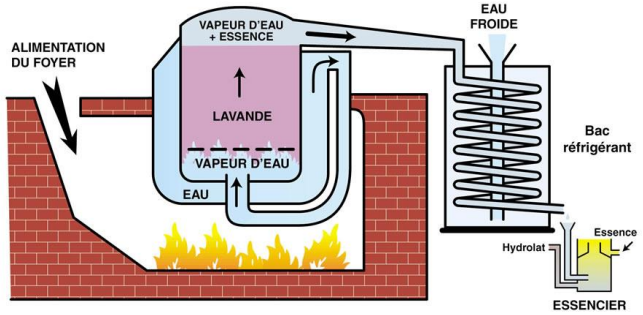
Yes, theoretically … no in fact

- typical and unique blend of volatiles (rose, lavender)
- secretion and accumulation in specialized anatomical structures (*e.g.* trichomes)

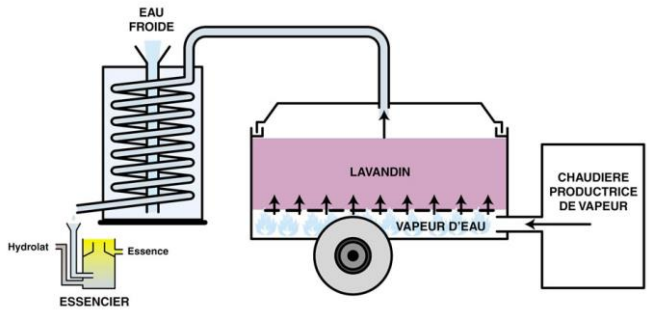
Essential oils: extraction techniques



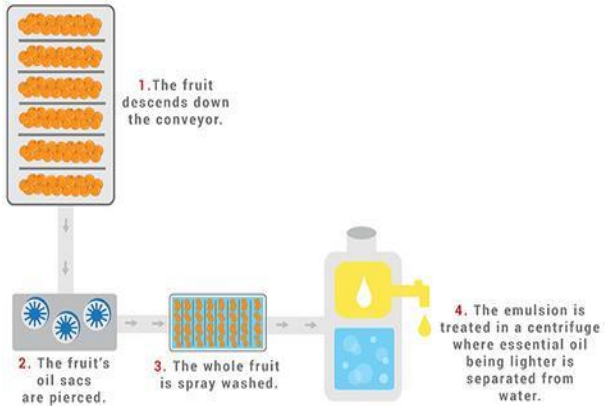
Hydrodistillation:
- very simple
- not expensive
- direct contact with plant material



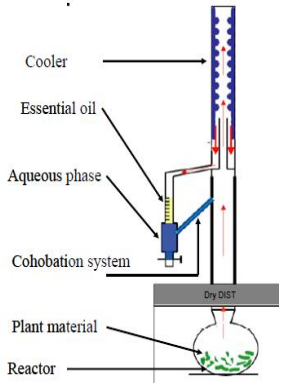
Steam distillation:
- more complex
- more expensive
- no direct contact with plant material



In field steam distillation:
- of practical use
- direct distillation after harvest
- limited volume



Pressing:
- used for citrus EOs
- EOs contain non volatile compounds
- not expensive

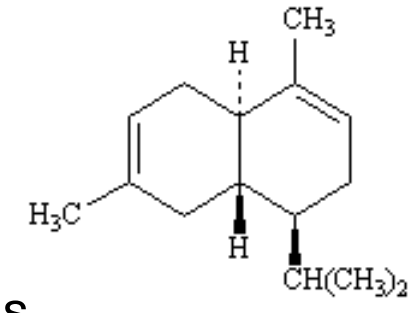


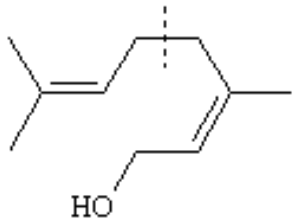
Microwave assisted techniques

Essential oils: composition

Mainly three pathways:

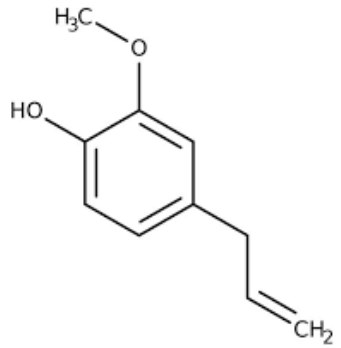
- Mevalonate ➔ sesquiterpenes
- Methyl-erythritol ➔ mono and diterpenes
- Shikimic ➔ phenylpropenes



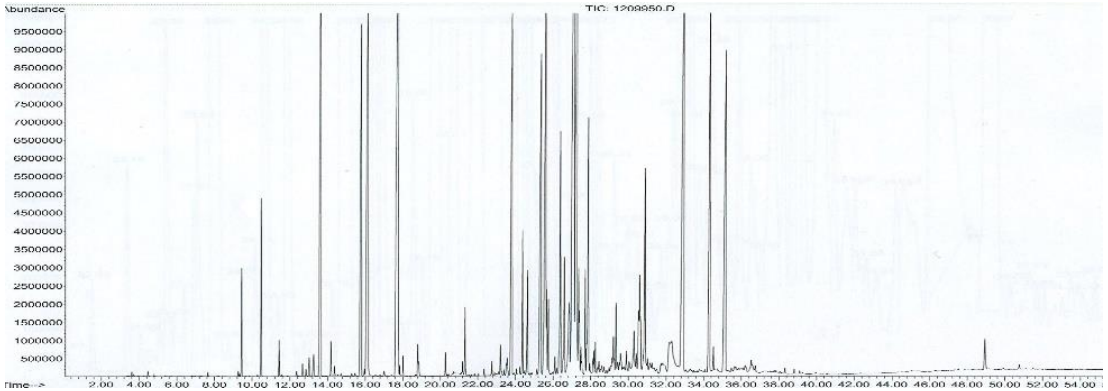


But also:

- Acids
- Alcohols
- Ketones
- Esters
- S and N containing compounds

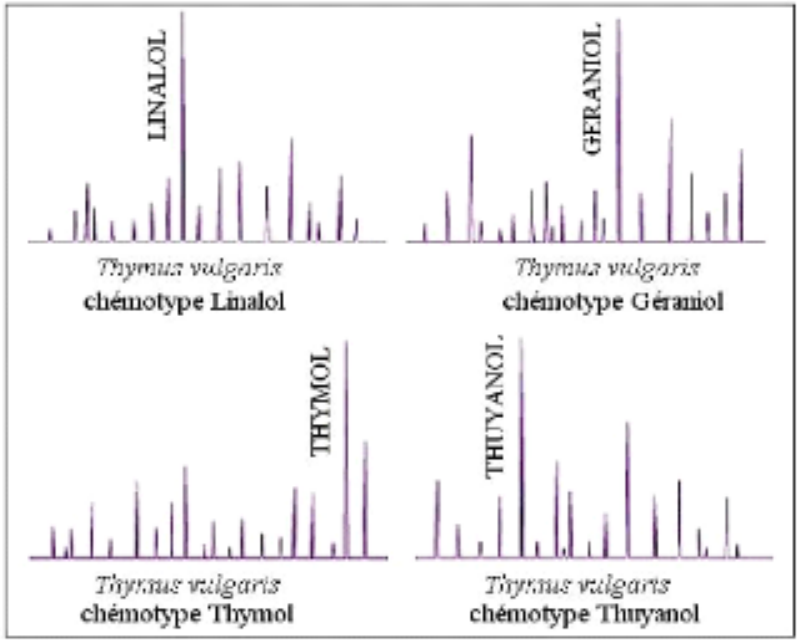


➔ very complex composition *e.g.* ylang ylang EO
> 450 compounds



Essential oils: composition

- Depends on the organ (cinnamon leaves: eugenol, cinnamon bark: cinnamaldehyde, cinnammon roots: camphor)
- Depends on the season
- Depends on the climate-soil-distillation (terroir effect)
- Presence of pathogens
- Chemotypes



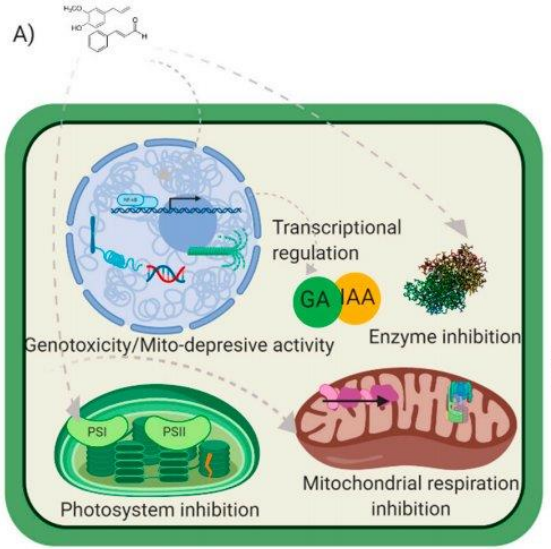
Thyme: 7 chemotypes

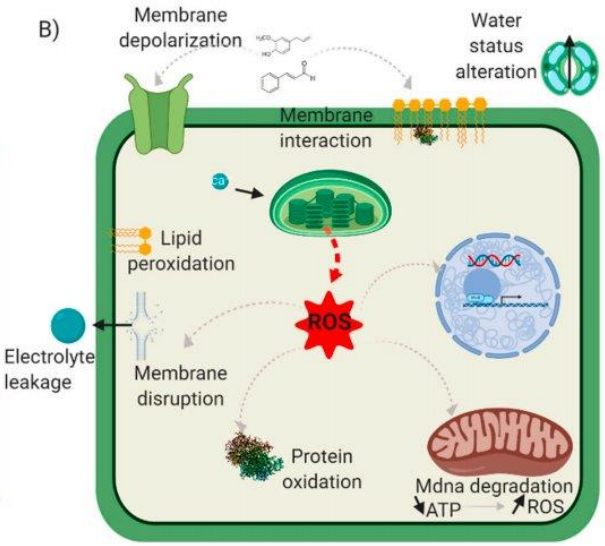
1. Linalool
2. Geraniol
3. Thymol
4. Thujanol
5. *Carvacrol*
6. *α-terpineol*
7. *Sabinene hydrate*

Pro and con of botanicals in a nutshell

- **Advantages:**
  - reduced side effects (human, not target organisms, environment)
  - low persistance
  - multiple action mode due to comples composition (less ressistance)
  - good acceptability by consumers

- **Constraints:**
  - flavour if volatile
  - variability (composition)➔ standardization
  - phytotoxicity
  - volatility
  - cost (only for high value crops?)
  - regulatory aspects (US versus EU)





Sustainability

- Numerous scientific studies
- Increasing number of publications
- Better elucidated modes of action
- Registered commercial products

- But what about sustainability?

- Botanicals and sustainability: 30,000 ref in *GS* but … because they are botanicals they must be a solution for sustainable agriculture!

International Journal of *Molecular Sciences* — MDPI

Review

Essential Oil-Based Bioherbicides: Human Health Risks Analysis

Chloë Maes [1,2], Jeroen Meersmans [3], Laurence Lins [4], Sandrine Bouquillon [1] and Marie-Laure Fauconnier [2,*]

foods — MDPI

Article

Insecticidal Activity of 25 Essential Oils on the Stored Product Pest, *Sitophilus granarius*

Sébastien Demeter [1,*], Olivier Lebbe [1], Florence Hecq [1], Stamatios C. Nicolis [2], Tierry Kenne Kemene [3], Henri Martin [3], Marie-Laure Fauconnier [3] and Thierry Hance [1]

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Review

Harnessing Plant's Arsenal: Essential Oils as Promising Tools for Sustainable Management of Potato Late Blight Disease Caused by *Phytophthora infestans*—A Comprehensive Review

Florian Martini [1,2,3,*], M. Haïssam Jijakli [4], Eric Gontier [3], Jérôme Muchembled [1,†] and Marie-Laure Fauconnier [2,†]

foods — MDPI

Article

Screening of Antifungal and Antibacterial Activity of 90 Commercial Essential Oils against 10 Pathogens of Agronomical Importance

Caroline De Clerck [1,*,†], Simon Dal Maso [1,†], Olivier Parisi [1], Frédéric Dresen [1], Abdesselam Zhiri [2] and M. Haissam Jijakli [1,*]

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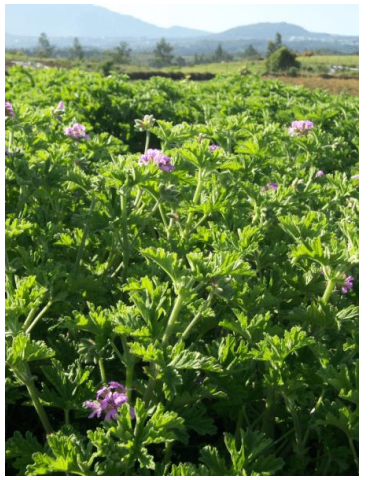
Review

Phytotoxicity of Essential Oils: Opportunities and Constraints for the Development of Biopesticides. A Review

Pierre-Yves Werrie [1,*], Bastien Durenne [2], Pierre Delaplace [3] and Marie-Laure Fauconnier [1]

Sustainability

Patchouli



Geranium

To produce botanicals we need plants:

often produced in the South for use in protecting our crops in the North

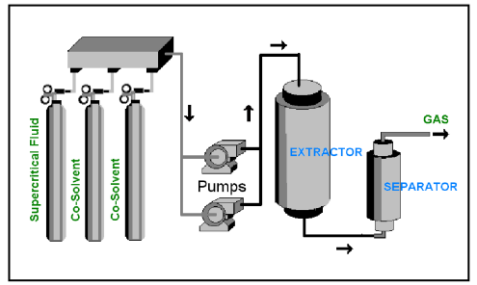
- **Cultivated plants**
  - ➔Require cultivation area that cannot be used for food production
  - ➔Production yields can be low (*e.g.* 1 ha of geranium ➔ 20-40 kg of essential oil)
  - ➔Requires watering (concurrence with food production)
  - ➔Requires labor often at a time when other fieldwork is ongoing
- **Wild plants**
  - ➔Depending on the organ harvested (trunk or roots), irreversible damage may occur to the plant / tree
  - ➔Intensive harvesting from nature can endanger biodiversity

Lemongrass

Zanthoxylum leprieurii

Sustainability

- **Extraction:**
  - Cold pressing (neem oil, *citrus* essential oils)
  - Solvants (water, ethanol, methanol but also ethyl acetate, benzene, acetone, chloroform, hexane) (*e.g.* algae extract)
  - Supercritical CO_2 (phenolics, terpenes, fatty acids)
  - Hydrodistillation / steam distillation for essential oils (wood, gas, petrol)



- **Purification:** conventional or greener techniques (energy, wastes)

- **Formulation:** co-formulants frequently coming from chemical synthesis

➔ The LCMN is working on sustainable strategies at different levels: plant concerns but also extraction and utilisation of botanicals

Solutions: plant concerns/extraction

1. Using entire plants (no extraction)

Boscia senegalensis leaf powder to protect maize against post-harvest insects

Tetrapleura tetraptera fruit powder to protect maize against post-harvest insects in Congo

Solutions: plant concerns

2. Strip-cultivation, intercropping, crop rotation

Plants containing botanicals can be included in

- Crop rotation
- Intercropping
- Strip cropping
- Contour cropping
- Relay cropping
- Valorized intercrop

Can be an advantage for the crop

- Diversification (*e.g.* Lamiaceae)
- Insect repellent
- Nematicide
- Pollinator attractant
- Weed control
- Sol structure, …

Caraway (*Carum carvi*) / cereals

Solutions: plant concerns

3. Using weeds / plants that do not require watering

- *Lantana camara* essential oil to protect stored food against insects in Ivory Coast

Composition, Seasonal Variation, and Biological Activities of *Lantana camara* Essential Oils from Côte d'Ivoire

Fatimata Nea [1,2,*], Didjour Albert Kambiré [1], Manon Genva [2], Evelyne Amenan Tanoh [1,2], Esse Leon Wognin [1,3], Henri Martin [2], Yves Brostaux [4], Félix Tomi [5], Georges C. Lognay [6], Zanahi Félix Tonzibo [1] and Marie-Laure Fauconnier [2]

- *Hyptis spicigera or Lippia alba* essential oils to protect stored food against insects (South and North Senegal respectively)

Solutions: plant concerns/extraction

4. Using local co-products / green extraction

- Barks are co-products that are undervalued in our regions due to their low calorific value (garden)
- Bark contains interesting secondary metabolites
- Bark essential oils extracted from local trees are tested for applications in crop and wood protection (insecticide, fungicide, herbicide)
- Water extraction (maceration and decoction) and bio-ethanol extracts are also tested

Solutions: plant concerns/extraction

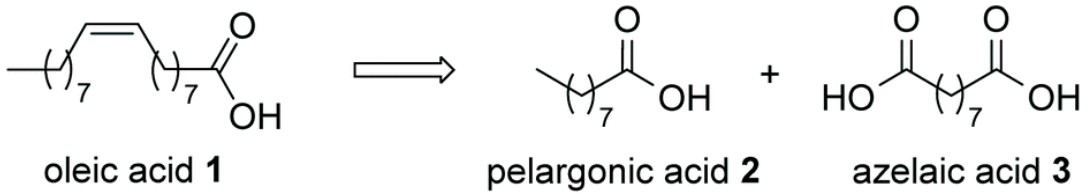
5. Allelopathy

- Allelopathy is a form of chemical interference in which one organism negatively affects another through the release of chemical compounds
- Production of allelochemicals has a cost for the crop
- In induced allelopathy, allelochemicals are released by the crops only in presence of weeds
- Exploiting induced allelopathy is an interesting strategy
- A lot of research to be done …

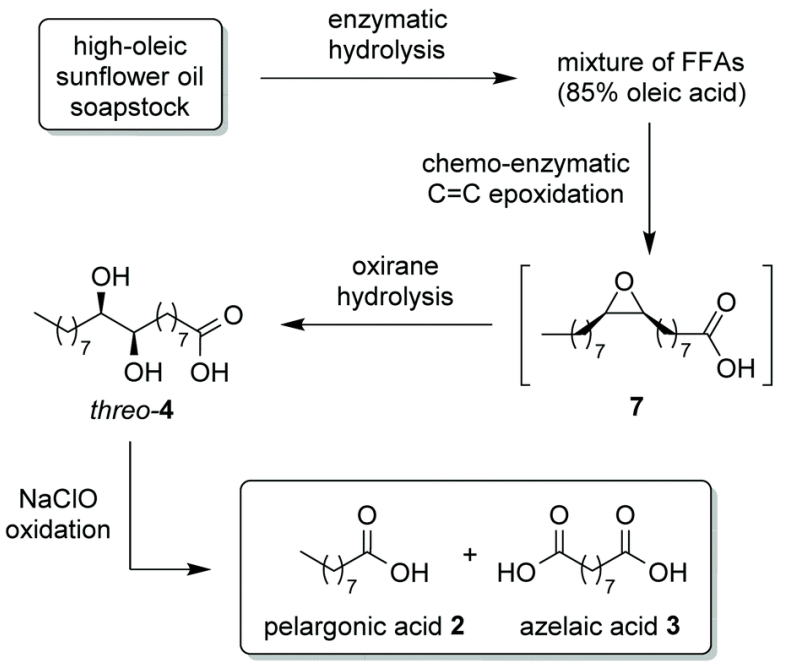
Solutions: plant concerns/extraction

6. Biotechnology strategies/synthesis of bio-based analogues/combination

- *In vitro* culture (hairy roots, shoot culture, cell suspension, callus) ➔ modified secondary metabolism
- Using bacteria / yeast for biotransformation / production
- Enzymatic biotransformation
- Chemical transformation of a bio-based substrate
- Combination of several strategies



Capparis spinosa



Solutions: utilisation ...

7. Use fewer botanicals thanks to precision agriculture

- Distinguish weeds/crops
- Botanicals are used where and when needed
- Cost?
- Efficacy?

Solutions: utilisation

8. Use fewer botanicals thanks to new injection techniques

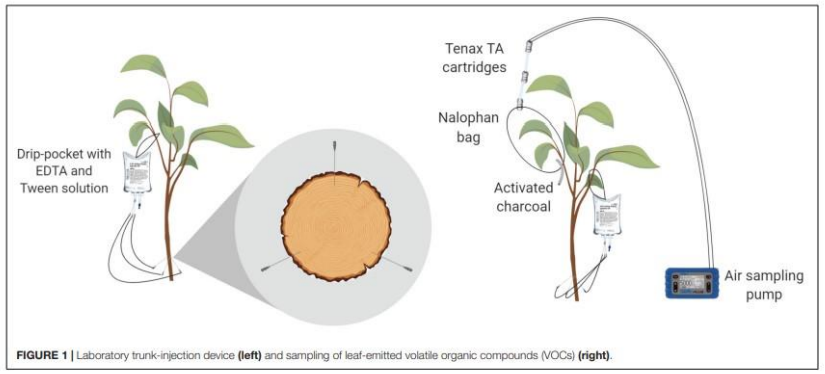
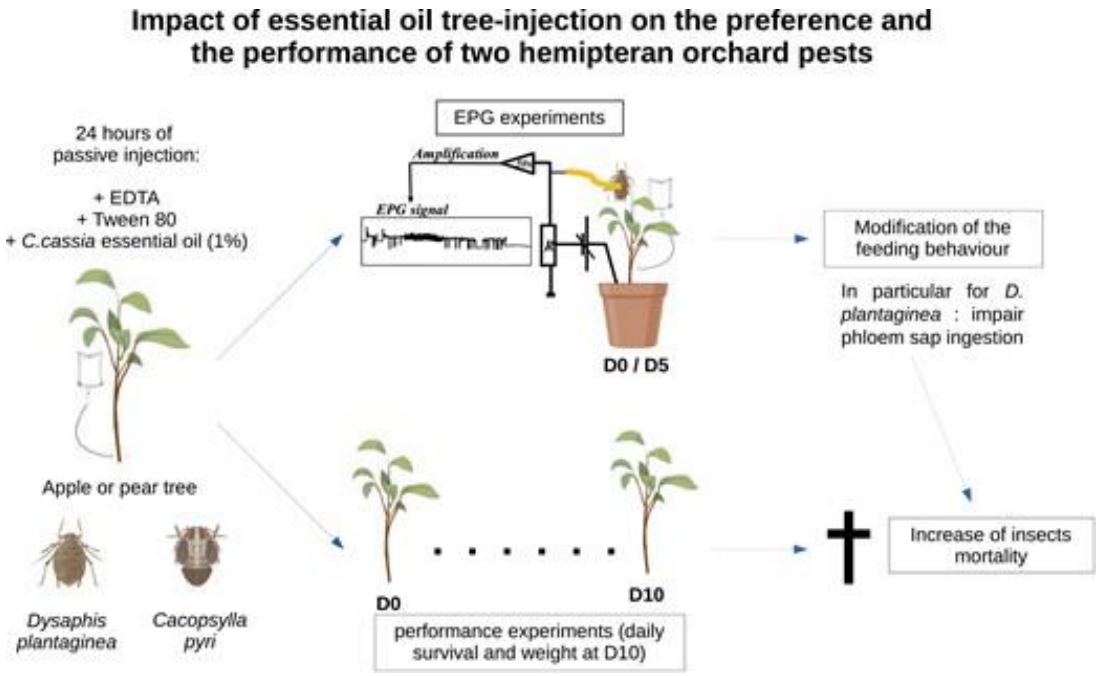


FIGURE 1 | Laboratory trunk-injection device **(left)** and sampling of leaf-emitted volatile organic compounds (VOCs) **(right)**.

- At laboratory scale, the EO components are emitted by leaves and affect insect pests
- In orcard conditions, emission of EO components but no effect on insect pests or pollinators



Biopesticide Trunk Injection Into Apple Trees: A Proof of Concept for the Systemic Movement of Mint and Cinnamon Essential Oils

Pierre-Yves Werrie[1†], Clément Burgeon[1†], Guillaume Jean Le Goff[2], Thierry Hance[2] and Marie-Laure Fauconnier[1]*

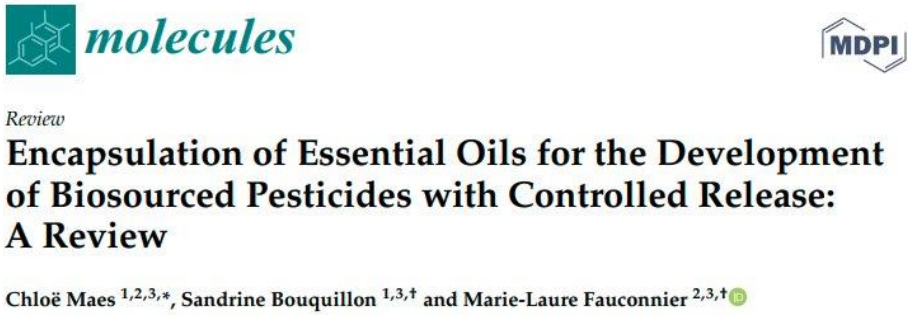
Solutions: utilisation

8. Use fewer botanicals thanks to encapsulation

Encapsulation for a slow release➔ reduce volatility, protect EOs against oxidation, increase activity period

- Various techniques: emulsification, coacervation, spray drying, complexation, ionic gelation, nanoprecipitation, film hydration method ➔ droplets, particles, capsules, and complexes from various sizes “micro” (1–1000 m) or “nano” (<1000 nm)
- Three matrixes are often used: alginate, chitosan, and cyclodextrin(for many techniques)

	Particles: matrix where EOs are dispersed
	Capsules: a membrane surrounds a core where are the EOs.
	Complexes: spatial disposition into an open structure
	Droplets: fine bubbles of the products dispersed in the solvent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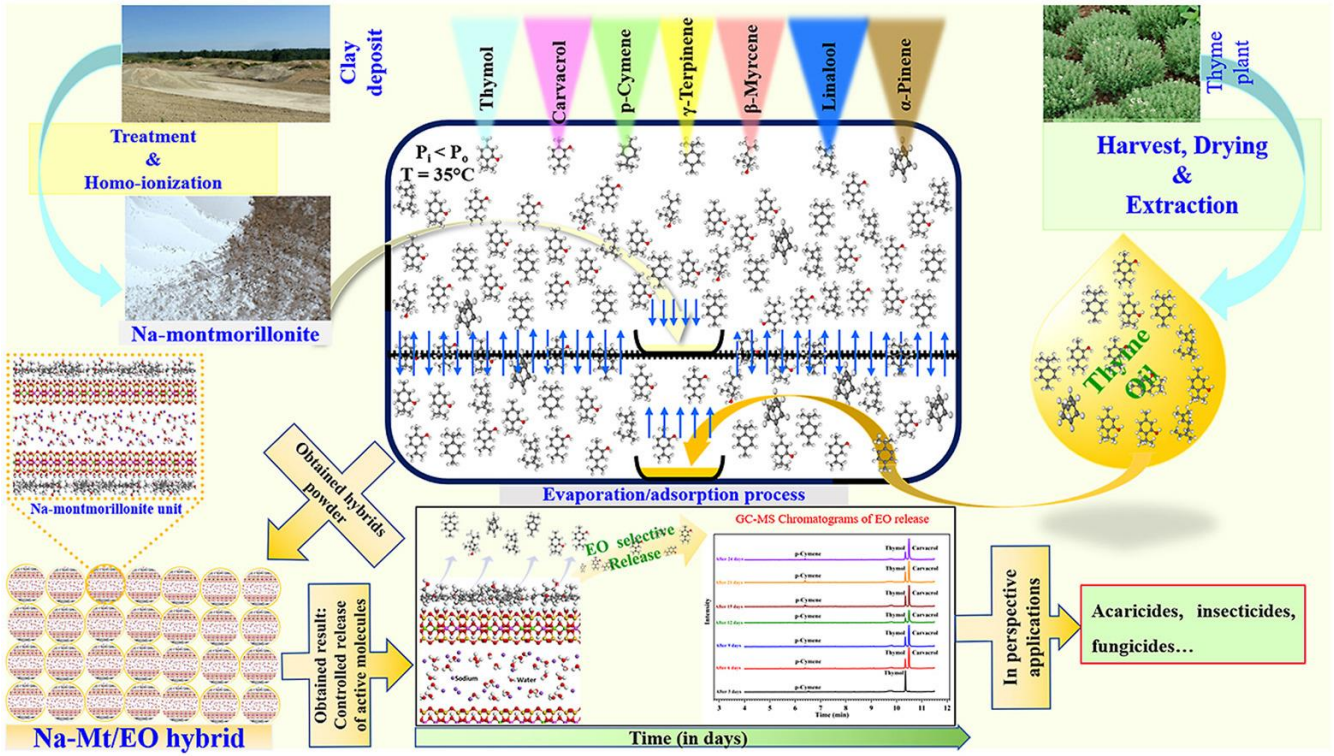
Review

Encapsulation of Essential Oils for the Development of Biosourced Pesticides with Controlled Release: A Review

Chloë Maes [1,2,3,*], Sandrine Bouquillon [1,3,†] and Marie-Laure Fauconnier [2,3,†]

Solutions: utilisation

8. Use fewer botanicals thanks to formulation



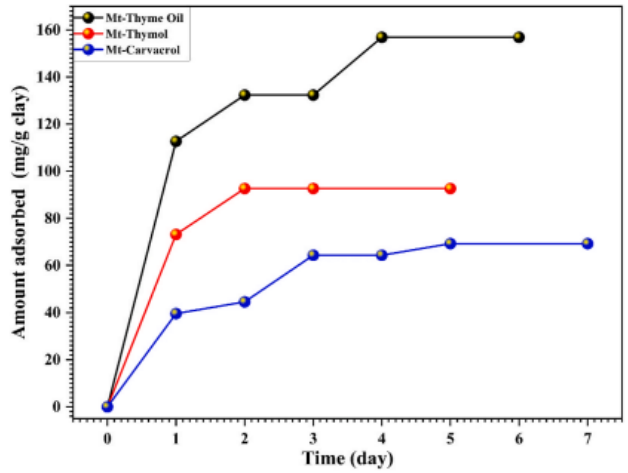


Fig. 2. Adsorption kinetics in gas phase of EO of thyme, thymol and carvacrol on Na^+-Mt.

- Montmorillonite treatment (HCl, NaOH)
- EO clay mineral hybrid
- Extended controlled release
- Insecticide mechanic effect on insects

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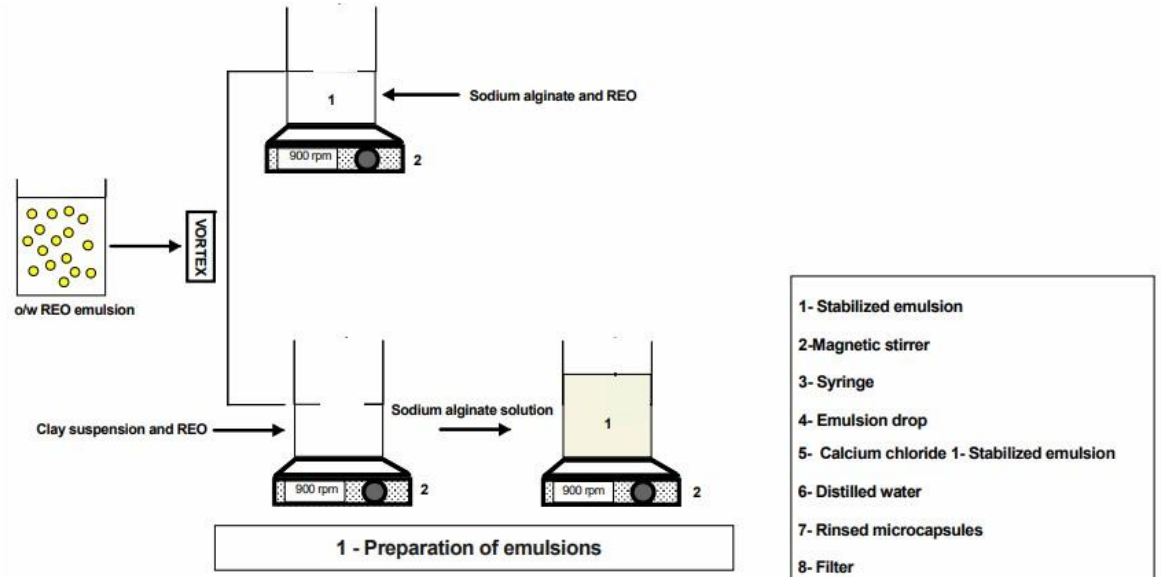
journal homepage: www.elsevier.com/locate/matchemphys

Montmorillonite nanoclay based formulation for controlled and selective release of volatile essential oil compounds

Kamal Essifi [a,*], Abdourahim Hammani [b], Doha Berraaouan [a], Ali El Bachiri [a], Marie-Laure Fauconnier [c], Abdesselam Tahani [a,**]

Solutions: utilisation

8. Use fewer botanicals thanks to formulation



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Article

Hybrid Microcapsules for Encapsulation and Controlled Release of Rosemary Essential Oil

Doha Berraaouan [1], Kamal Essifi [1], Mohamed Addi [2,*], Christophe Hano [3], Marie-Laure Fauconnier [4] and Abdesselam Tahani [1,*]

- Rosemary EO Calcium alginate and calcium alginate / montmorillonite microcapsules (micrometric and spheric)
- Higher thermal stability, higher loading capacity and encapsulation efficiency for hybrid µcapsules
- Slower release

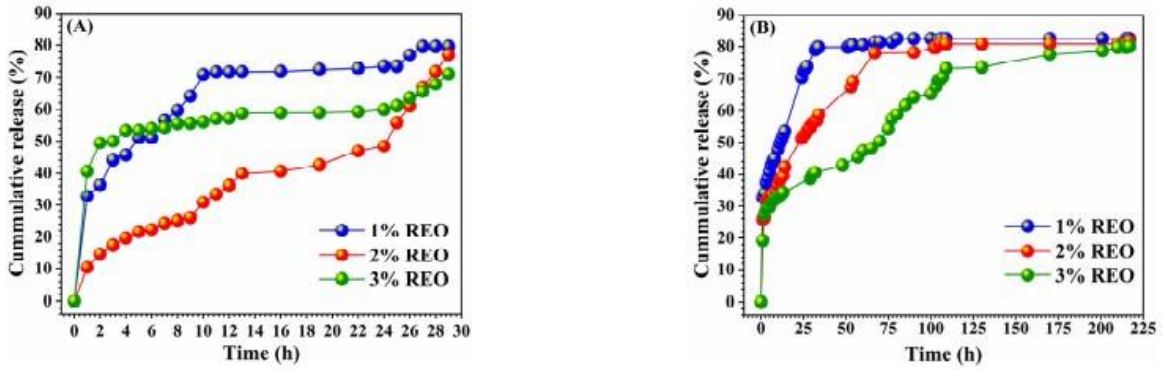


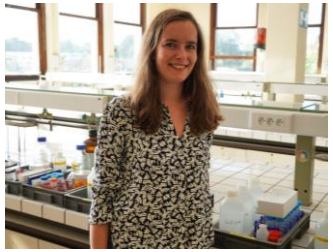
Figure 7. Kinetical release profiles of rosemary essential oil from CA-REO (**A**) and hybrid CA-MTN-REO (**B**) microcapsules in w/o medium.

Conclusions

- Next time you conduct research with botanicals, don't forget to consider **sustainability,** especially if these compounds are produced far from where they are used. Stop burying your head in the sand.
- Resorting to **sustainability labels** as well as studying the **life cycle** are avenues to explore in achieving this
- And when it comes time to formulate your botanical-based biopesticides, don't forget to check the origin of the **co-formulants**, which are mostly derived from petrochemistry.

- The use of **plants to protect other plants** through the valorization of **botanicals** is a fascinating subject that draws on **various disciplines**, with potential applications in both **Northern and Southern countries.**
- However, a **substantial journey** lies ahead to gain an in-depth understanding of the mechanisms at play and develop sustainable valorization strategies to replace conventional pesticides with bio-based solutions.

Clément Burgeon



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