

Insecticidal and repellent activities of *Cananga odorata* leaf essential oil (Lam.) Hook. F. & Thomson against a post-harvest pest of rice: *Sitotroga cerealella* Olivier

Adjalian Elvis

University of Abomey-Calavi

Philippe SESSOU

University of Abomey-Calavi

Alitonou Guy Alain

University of Abomey-Calavi

Michels Franck

Avlessi Félicien

University of Abomey-Calavi

Fauconnier Marie-Laure

Kossou Dansou

University of Abomey-Calavi

Dominique Sohounhloue (✉ csohoun@gmail.com)

University of Abomey-Calavi

Research Article

Keywords: *C. odorata*, essential oil, *S. cerealella*, toxicity, insecticide, repellence, rice

Posted Date: November 26th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-2257042/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Insecticidal and repellent activities of *Cananga odorata* leaf essential oil (Lam.) Hook. F. & Thomson against a post-harvest pest of rice: *Sitotroga cerealella* Olivier

Adjalian Elvis^{a,c}, Sessou Philippe^a, Alitonou Guy Alain^a, Michels Franck^b, Avlessi Félicien^a, Fauconnier Marie-Laure^b, Kossou Dansou^c, Sohounhloue K. C. Dominique^a

^aLaboratory for Studies and Research in Applied Chemistry (LERCA), Polytechnic School of Abomey-Calavi / University of Abomey-Calavi, 01 BP 2009 Cotonou, Benin

^bLaboratory of Chemistry of Natural Molecules, Gembloux Agro-Bio Tech, University of Liège, 2 Passage of the Deportees, 5030 Gembloux, Belgium

^cPlant Production Laboratory, Faculty of Agronomic Sciences / University of Abomey-Calavi, 01 BP 526 Cotonou, Benin

All correspondences should be addressed to Dominique Sohounhloue; csohoun@gmail.com.

Abstract

Today the use of plant extracts, in particular essential oils, is a natural alternative to synthetic insecticides in the fight against crop pests. The purpose of this research is to determine the chemical composition of the ylang-ylang *Cananga odorata* (Lam.) Hook. F. & Thomson leave essential oil and to evaluate on the one hand its ovicidal, larvicidal, insecticidal, anti-oviposition and insect repellent properties, and on the other hand its effectiveness in preserving the weight of the grains and the germination power of rice seeds against the Angoumois grain moth *Sitotroga cerealella* O., a major pest of rice in Benin. The essential oil from the leaves of the *C. odorata* (Lam.) Hook. F. & Thomson was obtained by hydro-distillation, and analysed by gas chromatography-mass spectrometry (GC-MS). The analysis showed that the oil contains 32 main compounds, the major ones being α -pinene (7.01%), lavandulyl acetate (7.19%), caryophyllene (30.33%), α -humulene (13.42%) and germacrene D (8.99%). Based on the findings of fumigation bioassays, the *Cananga odorata* (Lam.) Hook. F. & Thomson essential oil showed high toxicity against adult of the *S. cerealella* with values CL_{50} of 0.094 μ L/mL and CL_{90} of 0.46 μ L/mL. Similarly, our work has demonstrated that this oil has ovicidal and larvicidal or egg development retardant properties. It also caused strong oviposition inhibition activity of more than 97% in female of the *S. cerealella* O. and subsequently developed very good repellent or deterrent properties, with an average

repellence rate of 75.7% against the *S. cerealella* O. insect. These insecticidal effects preserved grain weight, with weight losses of at most 0.38% and a paddy rice seed germination rate of more than 80% at the lowest applied dose of 0.2µL/mL. The essential oil from the leaves of the *C. odorata* (Lam.) Hook. F. & Thomson can be used as an alternative to modern toxic synthetic chemicals, for protection against this important pest of grains in storage in Benin.

Keywords: *C. odorata*, essential oil, *S. cerealella*, toxicity, insecticide, repellence, rice.

1. Introduction

Food losses during storage due to pest infestation are a major problem in our societies, both in developed and developing countries, causing significant financial losses (Haff et al., 2004; Fornal et al., 2007; Gustavson et al., 2021). Stored cereals are, in fact, a food source for many insects, mites and fungi that degrade product quality and can be the source of 9 to 20% of net losses (Phillips et al., 2010). Insect pests play a critical role in a country's food insecurity, especially in developing countries where losses of agricultural products due to insects can reach more than 30%. Rice being one of the world's staple foods, it is infested by a wide range of storage pests including the *Sitotroga cerealella* (Olivier), *Sitophilus oryzae* L., *S. granarius* L., *Ryzopertha dominica* F., as well as the *Scirpophaga incertulas* W. and the *Scirpophaga innotata* W. (Ashamo and Akinnawonu, (2012); Sarwar, (2015). *Sitotroga cerealella* is quasi-cosmopolitan today, and includes almost the whole Europe, as well as areas as distant as Australia, Benin, Brazil, China, Indonesia, Japan, Samoa Islands and the United States. This is due to synanthropic behaviour, which allows it to be easily transported through international grain trade. It is an insect pest which attacks cereal grains (corn, wheat, barley, rice, etc.) both in ears in the field and in storages (attics, silos, etc.). Indeed, these microlepidopteran insects attack rice, an important cereal in Africa, where storage in farmers' fields and other forms of preservation are increasingly confronted with infestations of *Sitotroga cerealella*, which ultimately lead to a reduction in rice farmers' income, and that of seed producers and other actors in the rice processing or marketing chain (Seck, D. (1991) ; Guèye, M. T., et al., (2011). ; Cissokho, et al., (2015). ; Nanfack, et al., (2015) ; Togola, et al., (2010)). ; Kossou, et al., (1992). Under conditions of heavy infestation, stored produce can suffer losses of 100% (Mele, 2007). Attacks by the *S. cerealella* O. lead to a reduction in the weight of products, a reduction in the germination capacity of seeds and a loss of nutritional

and commercial value. Currently, stored product insect control relies primarily on the use of synthetic insecticides and fumigants (Zettler and Arthur, 2000). There is therefore considerable interest in the development of natural products that are relatively less damaging to mammalian health and the environment than existing conventional pesticides, as important alternatives to non-selective synthetic pesticides for controlling pests medically and economically (Isman, 2000, 2006). The use of herbal insecticides has played an important role in the traditional method of stockpile pest control in Africa and Asia (Bekele and Hassanali, 2001; Liu et al., 2007). More specifically, essential oils also have interesting properties to replace synthetic insecticides (Huang Y et al. 2020; Oliveira et al. 2017). The growing interest in essential oils as an alternative to synthetic pesticides stems from their characteristics (Compolo et al., 2018). The search for new biologically active molecules against populations of *Sitotroga cerealella* explored an Annonaceae grown in Benin. *Cananga odorata* (Lam.) Hook. F. & Thomson is a perennial tropical tree that grows natively in Southeast Asian countries such as the Philippines and Malaysia, and it also occurs naturally in several Pacific islands, including Australia. Subsequently, it was introduced to China, India, Africa and America due to its economic importance (Saedi et al., 2006). Ylang-ylang (*Cananga odorata* Hook. F. & Thomson) is one of the plants exploited for its flowers on a large scale, the essential oil of which is an important raw material for the perfume industry. Traditionally, the leaves of *C. odorata* are used for its antimicrobial, anti-biofilm, antioxidant, antivectorial, insecticidal, insect repellent, anti-inflammatory, sedative, relaxing and harmonizing effects on mood and cognitive performance, spermatotoxic, antihyperglycemic and antidiabetic (Loh Teng Hern Tan et al., 2015). The present study aims to evaluate under laboratory conditions some biological activities of the *Cananga odorata* leaf essential oil on the *Sitotroga cerealella* O., an important pest of rice in storage.

2. Material and methodology:

2.1. Plant material and distillation of volatile constituents

The *Cananga odorata* Hook. F. & Thomson leaves commonly called ylang-ylang were collected on the campus of Abomey-Calavi, in southern Benin, Atlantic department. They were identified and certified at the National Herbarium of the University of Abomey-Calavi whose filing number is YH 738/HNB, and stored in the laboratory between 18 and 20°C away from direct sunlight throughout the extraction period. The essential oils were extracted by

hydro-distillation of the leaves (450g) for 4 hours using a Clevenger-type extractor according to the method of the British Pharmacopoeia (British Pharmacopoeia, 1980). The essential oils were then dried over anhydrous sodium sulphate and analysed by GC/MS. Oil yields were calculated using the following formula:

$$\text{Efficiency (\%)} = \frac{\text{Mass of oil (g)}}{\text{Plant material mass (g)}} \times 100$$

The IR841 rice variety selected at the International Rice Research Institute (IRRI) and introduced to Benin in the 1970s is widely cultivated throughout the country. It is a variety suitable for both rain-fed lowland cultivation and irrigated cultivation and well appreciated by producers and consumers for the fragrant aroma of its grain and for its good production yield. The IR841 rice grains used in our laboratory tests come from a rice field without the addition of chemical fertilizers or synthetic pesticides.

2.2. Animal material

2.2.1. Insect breeding

The strains of *Sitotroga cerealella* O. used in mass rearing for this study come from the WARDA reserve (Benin). At the Plant Production Laboratory of the Faculty of Agronomic Sciences/University of Abomey-Calavi (Benin), they were reared under optimal conditions for reproduction and obtaining new generations ($T = 29 \pm 2^\circ\text{C}$, $\text{HR} = 70 \pm 10\%$). Adults from 0 to 24 hours of age from mass rearing are used for the various tests. In addition, one-day-old *S. cerealella* eggs were also used in bioassays.

2.2.2. Obtaining *Sitotroga cerealella* eggs

The *S. cerealella* O. eggs are obtained from a device whose main element is formed by two cardboard papers of black colour and of triangular "V" shape (Ellington, 1930). The black cardboard is chosen to better visualise the eggs which are of whitish or red colour depending on the age of the eggs. They are held at their bases by a staple and in the middle by glue. The set of two adjoining boxes is placed vertically in a glass jar so as to orient the base of the triangles towards the opening of the jar (photo 1). This device will allow the female *S. cerealella* O. to introduce her abdomen to deposit the eggs between the slits of the two adjoining triangles. The number of collection device jars is at least equal to the number of

experimental units to be infested. The eggs are taken (count as you go) using a fine pin so as not to crush them to be deposited on the different substrates.

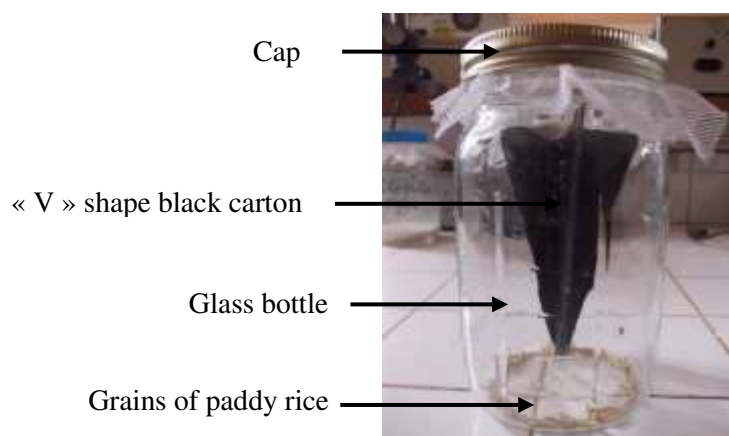


Photo 1: Device for obtaining the *S. cerealella* eggs

2.3. Volatile Constituents Analysis

GC/MS: The essential oils were analysed on a gas chromatograph Hewlett-Packard model 7890, coupled to a Hewlett-Packard MS model 5875, equipped with a DB5 MS column (30m x 0.25mm; 0.25 μ m), programming from 50°C (5 min) to 300°C at 5°C/min, 5 min hold. Helium was used as carrier gas (1.0 mL/min); injection was realised in split mode (1:30); injector and detector temperature were set at 250 and 280°C respectively. The MS operates in electron impact mode at 70 eV; electron multiplier: 2500eV; ion source temperature: 180°C; mass spectra data were acquired in sweep mode in the m/z 33-450 range. The identification of compounds was performed by comparison of mass spectra with mass spectra from libraries (Pal600 K, Wiley275, and NIST17) and by comparing retention indexes (RIs) calculated with RIs from the literature. The RIs were calculated following the injection of a mixture of n-alkanes C8–C30 (Sigma-Aldrich, Darmstadt, Germany) under the same chromatographic conditions.

GC/FID: The essential oils were analysed on a Hewlett-Packard Model 6890 gas chromatograph, equipped with a DB5 MS column (30m x 0.25mm; 0.25 μ m), programming from 50°C (5min) to 300° C at 5°C/min, 5min hold. Hydrogen was used as carrier gas (1.0 mL/min); injection in split mode (1:60); injector and detector temperature, 280 and 300°C respectively. The essential oil is diluted in hexane: 1/30.

2.4. Biological tests

The tests were all carried out in laboratory at a temperature of $29 \pm 2^{\circ}\text{C}$, a natural photoperiod; and a relative humidity of $70 \pm 10\%$.

2.4.1. Essential oil fumigation toxicity test on adult *Sitotroga cerealella*.

The method of Aiboud (2012) used for this test consisted in studying the fumigating effect of the essential oil of *Cananga odorata* on the mortality and emergence of young insects of *S. cerealella* O. The device consists of glass jars with a volume of 1 litre containing 50g of paddy rice (*Oryza sativa* L.) of the variety IR841, cotton with a mass of 0.3 g was suspended using a wire attached to the internal face of the lid of the jars (figure 1). After cotton treatments, in each jar ten (10) adult pairs of *Sitotroga cerealella* O. aged 0 to 24 hours, i.e. 10 males and twenty (20) females from mass breeding, all hermetically sealed. The mortality of populations of *S. cerealella* O. exposed to the insecticidal activity by fumigation of the treatment is observed for 72 hours of exposure time for the five (5) doses applied (0, 0.2, 0.5, 1, 5 $\mu\text{L/mL}$). The set is arranged in a complete random block device by application mode with three (03) repetitions. Overall, $5 \times 3 \times 1 = 15$ experimental units are set up. The number of dead individuals was counted after exposure. If no wing or leg movement is observed, the insect is considered dead. There is, in fact, in any treated population a natural mortality which is added to the mortality caused by this toxicant, the mortality rates have been corrected by Abbott's formula. This monitoring of mortality is continued until the death of all the insects. Then all the insects were separated from the grains. The experimental units were then observed at regular time intervals (24 h) for the emergence rate of young insects recorded and counted up to the 50th day after infestation.



Figure 1: Device for fumigation tests

2.4.2. Anti-oviposition activity of essential oil of *C. odorata* on female *Sitotroga cerealella* O.

The device used consists of glass jars of 1 litre capacity containing paddy rice (*Oryza sativa* L.) variety of IR841, the 0.3 g cotton mass was suspended using a wire fixed to the internal face of the lid of the jars with the concentrations of (0; 0.2; 0.5; 1 and 3 µL/mL). The control (or control) was carried out with 96% pure ethanol. Three replicates were performed for each dose. After 24 hours, a pair (1 male and 2 females) of *S. cerealella* O. from the farm, aged 0 to 24 hours, is placed on the plant material. In total, 5 x 3 x 1 = 15 experimental units are implemented for the test. Three (3) days after the counting of the eggs laid (hatched or not) on the grains and on the wall of the glass jar is carried out using a stereoscopic microscope.

2.4.3. Effect of treatments on egg development

The method of Aiboud (2012) used for this test consisted in studying the fumigating effect of the essential oil on the evolution of *S. cerealella* O. eggs.

With these same devices for the fumigation tests, 10 eggs of *S. cerealella* O. aged 0 to 24 hours are deposited on 50 g of paddy rice. Each of the doses applied, either on the cotton (0, 0.2, 0.5, 1 and 3 µL/mL) in three repetitions and the behaviours of the eggs were observed after 72 h. The grains of rice removed from the jars are placed in a Petri dish in order to be able to easily count the unhatched eggs under a binocular magnifying glass at a magnification of 40x then reintroduce into their respective jars and count as the larvae emerge from the grains treated up to the 45th day after treatment. The following variables were measured: egg hatch rate after 72h of exposure for each dose of essential oil; emergence rate of young *sitotroga cerealella* O. calculation of the viability rate of the larvae; the average development time of the insect.

The egg hatching rate after 72 hours of exposure for each dose of essential oil

$$\text{Rate of bursting of the ovums (\%)} = \frac{\text{Number of ovums hatched}}{\text{Total number of ovums}} \times 100$$

The emergence rate of *Sitotroga cerealella* O. up to the 45th day after treatment:

$$\text{Rate of emergence (\%)} = \frac{\text{Number of emerged adults}}{\text{Total number of ovums}} \times 100$$

The viability rate of *Sitotroga cerealella* O. larvae:

$$\text{Rate of viability of larvas (\%)} = \frac{\text{Number of emerged adults}}{\text{Number of ovums hatched}} \times 100$$

2.4.4. Repellence tests

The repellent action of plants was tested on *S. cerealella* O. using an olfactometer (figure 2) described by Sara Boeke et al., 2002.

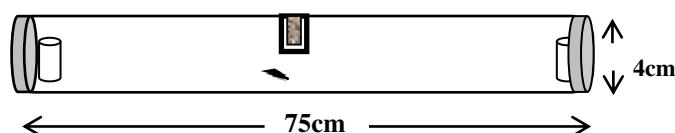


Figure 2: Olfactometer set-up.

At each end of the tube a small pot was placed containing either 10.0 g of paddy rice treated with ethanol only or 10.0 g of paddy rice mixed with a 0.1% dose essential oil solution, 0.5% and 1%. Ten (10) 24-48-hour old *S. cerealella* O. females are released one after another into the middle of the tube through the hole. The behaviour of the insects is observed and their position was noted every 15 min. All repellence tests were replicated 5 times for three or four days with new females for each replicate. The eight volatile extracts were tested once before the second series. The insects that have made a choice are those that have entered one of the jars containing the grains of rice or those that have reached the last twenty-five centimetres of the tube. For those who chose the middle of the tube, more insects made a choice as time passed. The percentage of insects repelled is calculated according to the following formula:

$$\text{Repellence percentage (\%)} = \frac{A - B}{A + B} \times 100$$

A = Average number of insects present in the untreated part (insects repelled)

B = Average number of insects present in the treated part (insects not repelled)

The average repellence rate of the essential oil was calculated and assigned, according to the previous classification (MC Donald, 1970), to one of the repellence classes ranging from 0 to V: class 0 (repellence rate (PR) < 0.1%), class I (PR= 0.1 - 20%), class II (PR= 20.1 - 40%), class III (PR= 40.1 - 60%), class IV (PR = 60.1 - 80%) and class V (PR= 80.1 - 100%).

2.4.5. Estimation of losses after treatment

To assess the damage caused by the insect *S. cerealella* O. on rice seeds, the grains of the substrate resulting from the treatments were collected, counted and weighed. The rate of grain dry matter weight loss was determined according to MCP (Method of Counting and Weighing) and MSVW (Method of Standard Volumetric Weight) (Panthenius, 1988). Two damage evaluation criteria are commonly used: the grain attack rate (A%) and the weight loss rate (B%) (CEEMAT 1988) calculated respectively by the following formulas.

$$A\% = \frac{Na}{Na+Ns} \times 100 \qquad B\% = \frac{PsNa - PaNs}{Ps(Na+Ns)} \times 100$$

2.4.6. Effect of treatment doses on the preservation of the germination capacity of paddy rice seeds

At the end of the tests, one hundred (100) seeds from each treatment based on the essential oil of *Cananga odorata* Hook. F. & Thomson including the controls, are mixed and divided into two batches of 100 seeds, were placed in Petri dishes the bottom of which contains a hydrophilic paper soaked in water. This device made it possible to subject the seeds to germination and to evaluate their germination power. Thus, all the germinated seeds were counted and the germination rates in the treatments were determined.

The germination rate was calculated according to Ogendo et al., (2004):

$$\text{Germination (\%)} = \frac{\text{Total number of grains germinated}}{\text{Total grain sampled and sown}} \times 100\%$$

2.5. Statistical analysis of data

The means of the various parameters studied (with the exception of those recorded at the level of the olfactometer) were subjected to analysis of variance (ANOVA) using the statistical analysis software SAS (Version 9.1). The Student-Newman-Keuls test was used to separate the means. (Dagnelie P., 1975).

Prior to analysis, count data (insect populations, number of eggs laid) were transformed to the “square root” function to correct for heterogeneity in the error variance (Sokal and Rohlf, 1995; Mcdonalds, 2009). As for the percentage of data (attack rate, weight loss, germination

rate, mortality rate, emergence rate) they have been transformed into the "Root Arcsin" function for the same reason. The Excel software made it possible to carry out these various transformations. The masses of the attacked seeds being continuous quantitative data and respecting the conditions of normalization and equality of variance did not undergo any statistical transformation. The values of the standard errors were calculated following a descriptive analysis of the means using SAS software. The results of the statistical tests are considered to be significantly different when the probability of the null hypothesis is less than or equal to 5%.

To more accurately assess the efficacy of oil toxicity by fumigation, we calculated the CL_{50} and CL_{90} . They were deduced from the regression plot by Finney's method. For this, the corrected mortality rates are converted into probits.

3. Result and discussion

3.1. Yield and chemical composition of *Cananga odorata* essential oil

The essential oil yield of *Cananga odorata* Hook. F. & Thomson leaves ($R=0.41\%\pm0.03\%$) harvested at Abomey Calavi Campus, Atlantique department, Benin is higher than those obtained by Jun Cheng et al., (2012) ($R=0.12\%$), China, and Harlinda Kuspradinia et al., (2016) ($R=0.04\%$) in Indonesia. The chromatographic analysis of the essential oil extracted from the leaves of *C. odorata* Hook. F. & Thomson contains 32 chemical compounds representing 100% of the weight of the essential oil. (Table 1). These results are a little bit different from those of Jun Cheng et al., 2012, who found 23 compounds in the leaves of *C. odorata* Hook. F. & Thomson in Baoshan city, Yuannan Province in China. This could be due to the difference in the geographical area of leaf collection or the difference in the soil composition of the harvesting locations, the harvesting period, the cultural practices and the extraction technique. The main compounds of the essential oil are α -pinene (7.01%), lavandulyl acetate (7.19%), caryophyllene (30.33%), α -humulene (13.42%) and germacrene D (8.99%). Monoterpenoids represent 11 of the 32 compounds, which corresponds to 23.92% of the whole oil, while 17 of the 32 constituents are sesquiterpenoids (72.08% of the crude essential oil).

Table 1. Yields and chemical composition of essential oil from *Cananga odorata* leaves.

Peak	R.T.	Name	RI	Pct Total
1	8.387	Alpha-pinene	937	7.01
2	8.756	Camphene	952	0.13
3	9.505	Beta-pinene	979	3.86
4	9.88	Beta-myrcene	992	0.84
5	10.864	Limonene	1031	1.09
6	12.709	Linalool	1100	2.53
7	12.811	Nonanal	1105	0.28
8	14.041	Citronellal	1156	0.40
9	14.33	Benzyl acetate	1168	0.34
10	14.538	Menthol	1176	0.30
11	14.982	Beta-fenchyl alcohol	1193	0.19
12	16.474	Geraniol	1257	0.36
13	17.245	Bornyl acetate	1289	0.21
14	18.427	Delta-elemene	1343	1.02
15	18.7	Alpha-cubebene	1355	0.28
16	19.304	Alpha-copaene	1382	2.19
17	19.416	Lavandulyl acetate	1387	7.19
18	19.518	Beta-bourbonene	1391	1.44
19	20.374	Caryophyllene	1432	30.33
20	20.486	Gamma-elemene	1438	2.11
21	21.048	Alpha-humulene	1465	13.42

22	21.187	Epi-bicyclosesquiphellandrene	1471	0.35
23	21.459	Gamma-muurolene	1484	0.69
24	21.593	Germacrene	1490	8.99
25	21.812	Alpha-muurolene	1501	1.02
26	21.994	Alpha-farnesene	1510	1.42
27	22.235	Copaene	1523	0.70
28	22.385	Delta-cadinene	1530	2.50
29	23.636	Caryophyllene oxide	1593	2.83
30	24.711	Tau-muurolol	1651	1.80
31	26.936	Benzl benzoate	1773	3.21
32	28.161	Beta-bisabolene	1844	0.99
Total				100.02%
monoterpenoids				23.92
sesquiterpenoids				72.08
Others				4.02
Yield = 0.41%±0.03%				

3.2. Adulticidal effects of the essential oil tested against *Sitotroga cerealella*

Table 2 presents the mortality rates recorded during the biological tests and the emergence observed according to the doses of essential oil applied.

Table 2: Toxicity caused by fumigation of the *C. odorata* leaves essential oil

Dose (μ l/ml)	Mortality (%)	Emerged
0	7,76 $\pm$ 1,11b	404,77 $\pm$ 40,76a
0,2	100 $\pm$ 0,00a	1,66 $\pm$ 0,33b
0,5	100 $\pm$ 0,00a	0 $\pm$ 0.00c
1.0	100 $\pm$ 0,00a	0 $\pm$ 0.00c
3.0	100 $\pm$ 0,00a	0 $\pm$ 0.00c
CV (%)	1,79	6,36
Probability	<0001***	<0001***

NOTE: 0: Ethanol treatment corrected with no-treatment control; <0001 *** = very highly significant difference; The means followed by the same letter are not significantly different at the beginning of ($p>0.05$) (Newman and Keuls test)

The essential oil from the leaves of *C. odorata* Hook. F. & Thomson has fumigant toxicity against adults of *Sitotroga cerealella* O. with 100% mortality recorded at the lowest dose of 0.2 μ L/mL with a complete absence of insect emergence from of the dose of 0.5 μ L/mL compared to the control group with 404 young *Sitotroga cerealella* O. counted. A highly significant difference was noted between the treatments. The slight reduction in emergence rates at low concentrations would result from the manifestation of the ovicidal or larvicidal effect of the active volatile extract, which would have destroyed the development of eggs or larvae. However, the low emergences observed during the tests could well come from eggs probably laid inside the walls of the pots. Regarding the insecticidal activities of the essential oil, our results corroborate the work of several researchers who have demonstrated the toxicity of essential oils by inhalation or fumigation against stored product pests (Keita et al., 2001; Lee et al., 2001 Kim et al., 2003; Shaaya et al., 1997; Thiam, Abdoulaye et al., 2021; Demeter, Sébastien et al., 2021). In addition, the essential oil from the leaves of *C. odorata* Hook. F. & Thomson has been shown to possess antiparasitic properties and could be considered to have the potential to be developed as a natural fumigant or insecticide for the control of insects in stored products Jun Cheng et al., (2012). The major advantage of

fumigation is that it facilitates the penetration of gases inside the grain and thus destroys the developing eggs, larvae and pupae (Benayad, 2008).

Table 3. Essential oil toxicity parameters on adult *S. cerealella* O. after fumigation.

Essential oil	n ¹	ddl ²	LC ₅₀ ^{ab}	LC ₉₀ ^{ab}	Slope ± SE	Chi square (X ²)	Prob.
<i>C.odorata</i>	30	1	0.094 (0.110 – 0.173)	0.46 (0.289 – 1.076)	3.20±1	10.11	0.0015

± SE: Standard error of the mean; ddl: liberty level; a: CL₅₀ and CL₉₀ µl/ml/L units, applied for 24 hours at 29°±2.; b: Lower and upper 95% fiduciary limits are shown in parentheses.

To further assess the toxicity efficacy of this oil, we calculated its CL₅₀ and CL₉₀. It is clear from this table 3 that the essential oil of *Cananga odorata* Hook. F. & Thomson seems to have significant efficacy. These results are confirmed by the CL₅₀ and CL₉₀ values obtained from a function of the regression line and which correspond to 0.094µl/ml and 0.46µl/ml (Table 3). Indeed, the CL₅₀ is lower than the first dose (0.2µl/mL), so that the CL₉₀ is between the first and the second dose.

The insecticidal activity of the ylang-ylang flowers essential oil was also studied by Phasomkusolsil and Soonwera, (2011) against the three types of adult mosquito species, including *Aedes aegypti* Linnaeus, *Culex quinquefasciatus* S. and *Anopheles dirus* Peyton & Harrison with CL₅₀ values (CL₅₀ = 9.77%, 8.82% and 4.99%) respectively. On the other hand, Jun Cheng et al., (2012) reported that the essential oil from the leaves of *C. odorata* (Lam.) Hook. F. & Thomson showed high contact toxicity against the stockpile pest, *Sitophilus zeamais* Motschulsky with an DL₅₀ value (DL₅₀= 33.14 pg / adult). The essential oil also possesses fumigation toxicity against *S. zeamais* Motschulsky with an CL₅₀ value (CL₅₀ = 14.77 mg/L) and overall showed potential for contact and fumigation toxicity against grain storage insects. This same study also showed that linalool, which is a competitive acetylcholinesterase inhibitor, could be the active component that explains the insecticidal activity of *C. odorata* (Lam.) Hook. F. & Thomson essential oil.

3.3. Evaluation of the anti-oviposition activity of the essential oil of *C. odorata* on the female of *S. cerealella*

The table 4 presents the effects of fumigation with *Cananga odorata* (Lam.) Hook. F. & Thomson essential oil on the oviposition capacity of *S. cerealella* females on its preferred host, paddy rice

Table 4: Eggs hatching rate of *Sitotroga cerealella* O according to the essential oil doses.

Dosage ($\mu\text{L/mL}$)	Eggs hatching rate $\pm\text{SE}$
0	53.33 $\pm$ 9.29a
0.2	0.66 $\pm$ 1.15b
0.5	0.0 $\pm$ 0.00b
1.0	0.33 $\pm$ 0.57b
3.0	0 $\pm$ 0.00b
CV (%)	23.70
Probability	<0.001***

NOTE: 0: Ethanol treatment corrected with no-treatment control; <0001 *** = very highly significant difference; The means followed by the same letter are not significantly different at the beginning of ($p>0.05$) (Newman and Keuls test)

A drastic decrease of 98.76% in the oviposition rate of females was noted for the fumigation treatments for the lowest dose 0.2 $\mu\text{L/mL}$ compared to the control which recorded an average oviposition rate of 53.33 eggs. Egg-laying activity was totally inhibited in females from a dose of 0.5 $\mu\text{L/mL}$. There is a highly significant difference ($p<0.001$) between the effects of the treatment doses on lay and are statistically different ($p<0.001$) from the control. We therefore observed a significant reduction in the number of eggs laid by the females during and/or after their exposure to the various essential oils compared to the control at the various doses. *Cananga odorata* essential oil remains more active on females, inhibiting their egg-laying by more than 90%. The reduction in egg laying observed in females of *sitotroga cerealella* O in the presence of essential oil would probably also be linked to the early death of some females or to the morbidity observed in some. Indeed, Soonwera, (2015) demonstrated the interesting deterrent effect of *C. odorata* (Lam.) Hook. F. & Thomson oil on

oviposition with an effective repellence value of 100% against the female housefly to undertake oviposition at both concentrations of 1,65 $\mu\text{L.cm}^2$ and 3,30 $\mu\text{L.cm}^2$. The inhibition of egg laying by *S. cerealella* O females could also be linked to a disruption of egg laying due to the volatile effect of the essential oil. This proves that the essential oil of *C. odorata* (Lam.) Hook. F. & Thomson would cause the retention of eggs by physical inability to lay eggs in females of this species of Lepidoptera. Moreover, the physiological disturbance induced by the volatile extract in insects has also been mentioned by Séri-Kouassi, (2004), Ketoh, (1998) and El-Nathal et al., (1994). The same is true for the work of Javaid and Poswal (1995) on the effect of clove powder on adults of *C. maculatus* Fabricius. However, it is worth emphasizing the theoretical value of these figures. Indeed, between what is done in jars and what happens in intensive farming, many factors can intervene which are not examined in this work.

3.4. Ovicidal and larvicidal properties of *C. odorata* essential oil

The table 5 presents the results of the effect of fumigation treatments according to dose on egg development on paddy rice.

Table 5: Eggs hatching rate, adult emergence and larval viability rates under the effect of essential oil fumigation on paddy rice.

Dose ($\mu\text{L/mL}$)	Eggs hatching rate (%)	Emergence (%)	Viability of larvae (%)	Duration of cycle of the insect, (ovum to the adult)
0	86.66 $\pm$ 3.33a	73.33 $\pm$ 3.33a	84.61 $\pm$ 5.77a	25.66 $\pm$ 1.52
0.2	3.33 $\pm$ 3.33b	3.33 $\pm$ 3.33b	100 $\pm$ 3.33a	34.33 $\pm$ 1.15
0.5	3.33 $\pm$ 3.33b	3.33 $\pm$ 3.33b	100 $\pm$ 3.33a	40,66 $\pm$ 1.6
1.0	0 $\pm$ 0.00b	0 $\pm$ 0.00b	0 $\pm$ 0.00b	-
3.0	0 $\pm$ 0.00b	0 $\pm$ 0.00b	0 $\pm$ 0.00b	-

Note: -: total absence of emergence of adult *S. cerealella* in the test; NOTE: 0: ethanol treatment corrected with the control without treatment; The means followed by the same letter are not significantly different at the beginning of ($p>0.05$) (Newman and Keuls test)

There was a significant difference ($p<.0001$) between the oil application rates for the parameters measured. *C. odorata* essential oil significantly reduced egg hatch rate to 100% from the lowest applied dose of 0.2 μ L/mL. This shows the ovicidal effects of the essential oil which were very remarkable. The emergence rates recorded in this test reveal the larvicidal effects of the essential oil of *C. odorata* (Lam.) Hook. F. & Thomson which killed 80% of emerging larvae for the low doses in the case of this treatment. It should be noted that from the high doses 1 μ L/mL, 3 μ L/mL, we found that the oil completely inhibits the hatching of eggs and the emergence of young adults of *Sitotroga cerealella* O, and led to an extension of the development cycle of the insect about nine (9) days to fifteen (15) days longer than the control for low doses of essential oil application. Such a reduction in the emergence rates would result from the manifestation of the ovicidal or larvicidal effect of the volatile extract which would have annihilated or prevented the development of the larvae. Calculated viability rates show that the essential oil controlled egg hatch better than larval hatch. Similar observations were made by Loh Teng, et al., 2015 on mosquitoes who found that 10% *C. odorata* flowers essential oil in soybean oil showed high ovicidal activities against three mosquito species tested. Likewise, his studies have shown that the essential oil of *Cananga odorata* (Lam.) Hook. F. & Thomson has ovicidal properties against several species of mosquitoes.

3.5. Repellence effect of the essential oil tested

The repellence rates for the different doses of *Cananga odorata* (Lam.) Hook. F. & Thomson leaf essential oil are summarized in table 6

Table 6: Rate (%) of olfactometer repellence of the essential oil of *C. odorata* leaves on adult *Sitotroga cerealella*

Dosage (%)	Repellence rate (%) ($\pm$ SD)
	<i>C. odorata</i>
0.1	59.5 $\pm$ 9.46
0.5	75.5 $\pm$ 8.74
1.0	92 $\pm$ 10.95
Mean ($\pm$ SD)	75.7 $\pm$ 3,87
Classe of repellence	IV

The different doses of essential oils (0.1%, 0.5% and 1.0%) caused a rate of 59.5%±9.46% repellence; 75.5%±8.74%; 92%±10.95%. This clearly shows that the repellence rate increases with dose. The average repellence is 75.7%±3.87% and belongs to repulsion class IV according to the classifications of MC Donald et al., 1970. These results corroborate those of Kaballero-Gallardo et al, (2011), Olivero -Verbel, et al., (2013), who showed that essential oil from *C. odorata* leaves has repellent activity against *Tribolium castaneum* Herbst, a red flour beetle that is known to be the pest associated with stored products, thus protecting stored products from insect damage. Indeed, in this study, *C. odorata* leaf essential oil was found to have the strongest repellent effect against *T. castaneum* Herbst at a concentration of 5 µL per gram of oats compared to other essential oils tested in the study. Other authors such as Olivero-Verbel et al., (2013); Caballero-Gallardo et al (2011) also demonstrated that *C. odorata* essential oil showed the highest repellence rate of 98% at 0.2 µg.cm⁻² after the two exposure times of 2 and 4 hours against *T. castaneum* Herbst, which suggests that it can be considered as excellent candidates for natural repellents. In addition, other studies have indicated that the *Cananga odorata* (Lam.) Hook. F. & Thomson essential oil possesses some degree of repellent activity against adult *A. aegypti* Linnaeus, *A. dirus* Peyton & Harrison and *C. quinquefasciatus* S. mosquitoes Fradin and Day, (2002), Soonwera et Phasomkusolsil, (2014, 2015). Most of the studies listed above have indeed shown that *C. odorata* (Lam.) Hook. F. & Thomson essential oils have demonstrated good repellent properties against different insect species, in this case against post-harvest insect pests. Based on these results, *C. odorata* (Lam.) Hook. F. & Thomson oil has repellent activity against a major rice pest in Benin. It can therefore be a safer alternative to modern toxic synthetic chemicals.

3.6. Effects of essential oil doses on paddy rice grains weight preservation

The table below shows the rates of attack and weight loss caused by the *S. cerealella* insect populations on rice seeds from essential oil treatments.

Table 7: Rates of attacked rice (A) and weight loss (B) caused by the *C. odorata* essential oil in the fumigation method.

Dose	A (%)	B (%)
------	-------	-------

($\mu\text{l/mL}$)		
0	25.44 $\pm$ 0.93b	20.31 $\pm$ 0.28b
0,2	0.45 $\pm$ 0.02c	0.3 $\pm$ 0.03c
0,5	0.3 $\pm$ 0.01c	0.1 $\pm$ 0.01c
1.0	0.01 $\pm$ 0.0c	0.00 $\pm$ 0.00c
3.0	0.0 $\pm$ 0.00c	0.00 $\pm$ 0.00c
CV (%)	6.90	3.02
Probability	<0001***	<0001***

NOTE: 0: Ethanol treatment corrected with the control without treatment; <0001 *** = very highly significant difference; The means followed by the same letter are not significantly different at the beginning of ($p>0.05$) (Newman and Keuls test)

At the end of the biological tests, the attack rates and the weight losses recorded at the level of the treatments are at most, respectively 0.45% and 0.3% compared to the control where the insects caused up to 25% of the attacks on the grains for an estimated 20% weight loss. No losses were recorded for the highest doses of this fumigation treatment. This activity of the essential oil of the *C. odorata* leaves observed which would have preserved the weight of rice grains subjected to the infestation of *Sitotroga cerealella* O adults can be due to the ovicidal, larvicidal or insecticidal or anti-feedant activities of the rice essential oil whose main compounds of the volatile extract, would have acted alone or in synergy with other minor constituents in the preservation of the weight of rice grains during all the time of experimentation.

3.7. Effect of essential oil on preservation of germination power of paddy rice seeds

The figure 3 shows the graph illustrating the percentages of germinated paddy rice grains according to the different doses of essential oil.

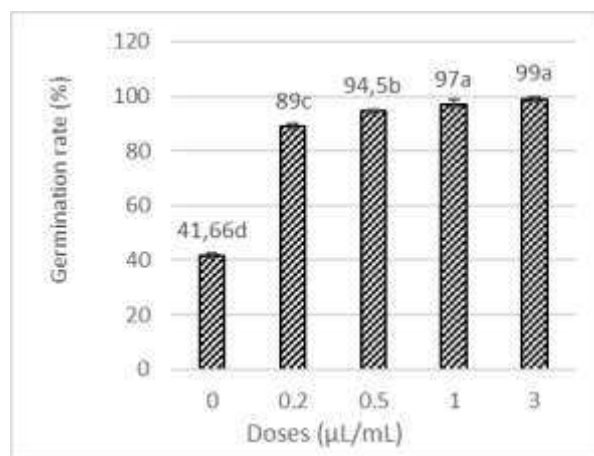


Figure 3: Rice germination rate per fumigation according to the essential oil doses

Note: ethanol treatment corrected with the control without any treatment. The means followed by the same letter are not significantly different at the beginning of ($p>0.05$) (Newman and Keuls test).

For the grains resulting from the fumigation treatments, it is observed that the essential oil of *Cananga odorata* (Lam.) Hook. F. & Thomson preserved the germination power of the infested paddy rice seeds. The germination rate recorded at the lowest dose was greater than 80% and reached 99% at the highest dose of 3µL/mL. In all cases, the germination rates recorded with the treatments are much higher than the germination rates recorded with the control, which was 41.66% and the germination rates of 80% recommended by the National Agricultural Research Institute of Benin. Indeed, according to the statistical analysis of the data, there is a highly significant difference ($P<0.001$) between the germination rates according to the dose. Germination tests showed that plant material tested against *S. cerealella* had no visible negative effects on seed germination ability. Similarly, according to Ketoh et al., (2002) and Glitho et al., (2008), the presence of residues in treated seeds does not affect their germination capacity. Contrary to the present results, some oils may be phytotoxic Werrie, Pierre-Yves et al, (2020). the study by Paranagama et al. (2003) showed

that treatment with *C. citratus* oil reduced the germination capacity of paddy compared to the uninfested lot. All the biological tests have confirmed that the treatment of this cereal with the *Cananga odorata* leaves essential oil can be very effective in the control of this predatory pest of rice in hot countries of the world and corroborate the results of other authors such as than Vincent et al., (2000); Vincent et al., (2003); Regnault-Roger et al., (2008); Philogene et al., (2008); Togola et al., (2010); Ashamo et al., (2012); Cissokho et al., (2015); Compolo et al., (2018); Thiam et al., (2021); Demeter et al., (2021) who highlighted the biological activities of essential oils in the protection of foodstuffs in storage.

Conclusion

The composition of the essential oil derived from the *C. odorata* leaves was determined by GC-MS. The study demonstrated that the essential oil from the *C. odorata* leaves exhibits high fumigation toxicity against *Sitotroga cerealella* O at different stages of development and also exhibits low phytotoxicity to germinated rice grains, reducing pest insects' attacks and preserving their weight. These results suggest that the essential oil from the *C. odorata* leaves has potential for development as a new natural insecticide/fumigant for the preservation of stored products. However, for the practical use of the essential oil, additional studies are necessary for the research among others, on the encapsulation of the oil for a slow release, on its mode of action on the insects, on the formulation of a quality bio-pesticide to improve the efficacy and stability of the product and finally on the harmlessness of this essential oil for humans.

Acknowledgements

The authors would like to thank the Polytechnic School of the University of Abomey-Calavi (Benin) and the Laboratory of Chemistry of Natural Molecules, Gembloux Agro-Bio Tech, University of Liège, 2 Passage of the Deportees, 5030 Gembloux, Belgium for their material support. They also thank Professor Aristide ADOMOU of the National Herbarium of Benin

for the identification of the plant. The authors have a pious thought for the late Dr Noudogbessi Jean-Pierre for his scientific contribution to this research (may he rest in peace).

Declaration

We hereby declare that the content and authorship of the submitted manuscript has been approved by all the authors. We further confirm that the submitted manuscript and all of the reported work are entirely original and carried out at the University of Abomey-Calavi, Abomey-Calavi and Université of Liège, Belgium. The results/data/figures in this manuscript have not been published elsewhere, nor are they under consideration by another publisher. All the material is owned by the authors and/or no permissions are required. We declare that all the authors have no conflicts of interest in this research, and we have seen and approved the final version submitted.

Ethical Approval

Ethical approval is not required for this study. Indeed, the study didn't involve both human and/ or animal.

Competing interests

We declare that we have no competing interests as defined by Springer, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

Author Contributions Statement

Conceptualization E.A., PS., KD and DS.; methodology, EA., PS., MF., MLF., GAA, FA. KD and DS.; software, EA.; formal analysis, EA, MF and MLF.; data curation. EA., PS., MF., MLF., GAA, FA. KD and DS.; writing—original draft preparation, EA., PS., MF., MLF., GAA, FA. KD and DS.; writing—all authors reviewed and edited the manuscript; supervision, KD and DS.; project administration, KD and DS.; funding acquisition, NO; All authors have read and agreed to the published version of the manuscript.

Funding

The funds required for this study were provided by authors

Availability of data and materials

Not applicable

References

1. Adams, R.P., 1989. Identification of Essential Oils by Ion Trap Mass Spectroscopy. 1st Edn., Academic Press, San Diego, ISBN-10: 0120442302, pp: 302.
2. Agbobli, C.A., K. Tetevi and L.T. Itra., 2004. Politiques de sécurité alimentaire au Togo: Cas de l'opération de joint-venture avec les riziculteurs pour la promotion de la production locale du riz compétitif
3. Aiboud, K., 2012. Etude de l'efficacité de quelques huiles essentielles à l'égard de bruche de Niébé *Callosobruchus maculatus* (Coleoptera: Bruchidae) et impacts des traitements sur la germination des graines de *Vigna unguiculata* (L.) Walp. Mémoire de magister en biologie et écologie des populations et des communautés. Université Mouloud Mammeri de Tizi Ouzou
4. Ashamo, MO., Akinnawonu O., 2012. Insecticidal efficacy of some plant powders and extracts against the Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae) Archives of Phytopathology and Plant Protection Volume 45, Issue 9, pages 1051-1058
5. Bekele, J., Hasanali, A., 2001. Blend effects in the toxicity of the essential oil constituents of *Ocimum Kilimands* and *Ocimum kenyense* (Labiatae) on two post-harvest pest insects. *Phytochemistry* 57, 385-391.
6. Benayad, N., 2008. Les huiles essentielles extraites des plantes médicinales marocaines: Moyen efficace de lutte contre les ravageurs des denrées alimentaires stockées. Thèse de doctorat, Université Mohammed V, Agdal Faculté des Sciences de Rabat.
7. Boeke, SJ, Baumgart, IR, Van Loon, JJA, Van Huis, A., Dicke, M., Kossou, DK., 2004. Toxicity and repellence of African plants traditionally used for the protection of stored cowpea against *Callosobruchus maculatus*. *Journal of Stored Product Research*. 40 (4). 2004, 423-438.
8. Caballero-Gallardo, K., Olivero-Verbel, J., and Stashenko, E. E., 2011. Repellent activity of essential oils and some of their individual constituents against *Tribolium*

castaneum herbst, *Journal of Agricultural and Food Chemistry*, vol. 59, no. 5, pp. 1690, 1696, 2011.

9. Campolo, O., Giunti, G., Russo, A., Palmeri, V., Zappala L., 2018. Essential Oils in Stored Product Insect Pest Control. *J. Food Qual.* 2018 :6906105. doi: 10.1155/2018/6906105.
10. Centre d'Etude et d'Expérimentation du Machinisme Agricole et Tropical (CEEMAT)., 1988. *Conservation des Grains en Régions Chaudes : Techniques Rurales en Afrique*, Centre d'Etude et d'Expérimentation du Machinisme Agricole et Tropical (CEEMAT), Paris, France, 1988.
11. Cissokho, P. S., Gueye, M. T., Sow, E. H., & Diarra, K. (2015). Substances inertes et plantes à effet insecticide utilisées dans la lutte contre les insectes ravageurs des céréales et légumineuses au Sénégal et en Afrique de l'Ouest. *International Journal of Biological and Chemical Sciences*, 9(3), 1644-1653. (Burkina Faso)
12. Dagnelie, P., 1975. *Théorie et Méthodes statistiques. Applications agronomiques*. Les Presses Agronomiques de Gembloux A.S.B.L. Avenue de la faculté, 22-5800 Gembloux (Belgique).
13. Demeter, S., Lebbe, O., Hecq, F., Nicolis, S. C., Kenne Kemene, T., Martin, H., ... & Hance, T. (2021). Insecticidal activity of 25 essential oils on the stored product pest, *Sitophilus granarius*. *Foods*, 10(2), 200.
14. El-nahal, A. K. M., Schmidt, G. H., and Risha, E. M., 1994. Influence of vapours of *Acorus calamus* L oil on the reproductivity of some stored-product Coleoptera. *Pakistan J. Entomol. Karachi* 9, 21-27.
15. FAO., 2022. *FAOSTAT Database*. <http://faostat3.fao.org/faostat-gateway/go/to/download/Q/QC/E> (consulté le 20 mai 2022).
16. Fornal, J., Jeliński, T., Sadowska, J., Grundas, S., Nawrot, J., Niewiada, A., Warchalewski, J.R., Błaszczak, W., 2007. Detection of granary weevil *Sitophilus granarius* (L.) eggs and internal stages in wheat grain using soft X-ray and image analysis. *J. Stored Prod. Res.* 2007; 43:142, 148. Doi: 10.1016/j.jspr.2006.02.003.
17. Foua-Bi, K., 1993. Produits naturels utilisés dans la protection des stocks en Afrique noire. In Thiam, A., Ducommun, G. Eds: *Protection naturelle des végétaux en Afrique*. Enda, Dakar, 85-100 p.
18. Fradin, M. S., and Day, J. F., 2002. "Comparative efficacy of insect repellents against mosquito bites, *The New England Journal of Medicine*, vol. 347, no. 1, pp. 13–18, 2002.

19. Glitho, I. A., Ketoh, KG., Nuto, PY., Amevoin, SK., Huignard, L., 2008. Approches non toxiques et non polluantes pour le contrôle des populations d'insectes nuisibles en Afrique du Centre et de l'Ouest. 207-217. In Regnault-Roger, C, Philogène, B.JR. et Vincent, C (Eds). Biopesticide d'origine Végétale 2 édition. Lavoisier, TEC & DOC, Paris, 550 p.
20. Guèye, M. T., Seck, D., Wathelet, J. P., & Lognay, G. (2011). Lutte contre les ravageurs des stocks de céréales et de légumineuses au Sénégal et en Afrique occidentale: synthèse bibliographique. Biotechnologie, Agronomie, Société et Environnement, 15(1).
21. Gustavsson, J., Cederberg, C., Sonesson, U., Van Otterdijk, R., Meybeck, A., 2021. Global Food Losses and Food Waste Extent, Causes and Prevention. [(accessed on 18 January 2021)]; Available online: <http://www.fao.org/3/a-i2697e.pdf>
22. Haff, R.P., Slaughter, D.C., 2004. Real-time x-ray inspection of wheat for infestation by the granary weevil, *Sitophilus granarius* (L.) Trans. ASAE. 2004; 47:531–537. Doi: 10.13031/2013.16022.
23. Huang, Y., Liao, M., Yang, Q., Shi, S., Xiao, J., Cao, H., 2020. Knockdown of NADPH-cytochrome P450 reductase and CYP6MS1 increases the susceptibility of *Sitophilus zeamais* to terpinen-4-ol. Pest. Biochem. Phys. 2020 ;162 :15–22. doi: 10.1016/j.pestbp.2019.07.008.
24. Isman, M. B., 2000. Plant essential oils for pest and disease management. Crop Protection. 19: 603-608.
25. Isman, M. B., 2006. Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. Ann. Rev. Entomol., 51: 45-66.
26. J. Cheng, K., Yang, N. N., Zhao, X. G., Wang, S. Y., Wang, and Z. L. Liu., 2012. Composition and insecticidal activity of the essential oil of *Cananga odorata* leaves against *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae), Journal of Medicinal Plants Research, vol. 6, no. 19, 2012.
27. J. Olivero-Verbel, I., Tirado-Ballesteras, K., Caballero-Gallardo, and Stashenko, E. E., 2013. Essential oils applied to the food act as repellents toward *Tribolium castaneum*, Journal of Stored Products Research, vol. 55, pp. 145, 147, 2013.
28. Javaid, I., and Poswal, M. A. T., 1995. Evaluation of certain spices for the control of *Callosobruchus maculatus* (Fabricius) (Coleoptera: Bruchidae) in cowpea seeds. African Entomol., 3, 87-89.

29. Kéita, S. M., Vincent, C., Schmit, JP., Arnason, JT., Bélanger, A., 2001. Efficacy of essential oil of *Ocimum basilicum* L. and *O. gratissimum* L. applied as an insecticidal fumigant and powder to control *Callosobruchus maculatus* (Fab.) (Coleoptera: Bruchidae). *Journal of Stored Product research* 37, 339-349.
30. Ketoh, G. K., Glitho, IA., Huignard, J., 2002. Susceptibility of the bruchid *Callosobruchus maculatus* (Coleoptera: Bruchidae) and its parasitoid *Dinarmus basalis* (Hymenoptera: Pteromalidae) to three essential oils. *Journal of Economic Entomology*, 95(1), 174-182
31. Ketoh, K. G., 1998. Utilisation des huiles essentielles de quelques plantes aromatiques au Togo comme biopesticides dans la gestion des stades de développement de *Callosobruchus maculatus* (Coleoptera: Bruchidae). *Thèse de Doctorat*, Univ. du Bénin, Lomé, 141 p.
32. Kim, S., Roh, L., Kim, D., Lee, H., Ahn, Y., 2003. «Insecticidal activities of aromatic plant extract and essential oils against *Sitophilus oryzae* and *Callosobruchus chinensis* Fab». *Journal of Stored Products Research* 39, 293-303.
33. Kossou, D., & Bosque-Perez, N. A. (1992). Insectes nuisibles du maïs entreposé; biologie et méthodes de lutte: Guide de recherche de IITA, No. 32.
34. Lee, SE., Lee, BH., Choi, WS., Park, BS., Kim, JG., Campbell, BC., 2001. Fumigant toxicity of volatile natural products from Korean spices and medicinal plants towards the rice weevil *Sitophilus oryzae* L. *Pest Management Science* 57(6), 548-553.
35. Liu, ZL., Goh, SH., Ho, SH., (2007). Screening of Chinese medicinal herbs for bioactivity against *Sitophilus zeamais* Motschulsky and *Tribolium castaneum* (Herbst). *J. Stored Prod. Res.*, 43: 290-296.
36. Loh Teng Hern Tan., Learn Han Lee., Wai Fong Yin., Chim Kei Chan., Habsah Abdul Kadir., Kok Gan Chan., Bey Hing Goh., 2015. "Traditional Uses, Phytochemistry, and Bioactivities of *Cananga odorata* (Ylang-Ylang)", *Evidence-Based Complementary and Alternative Medicine*, vol. 2015, Article ID 896314, 30 pages, 2015. <https://doi.org/10.1155/2015/896314>
37. Maes, C., Bouquillon, S., & Fauconnier, M. L. (2019). Encapsulation of essential oils for the development of biosourced pesticides with controlled release: A review. *Molecules*, 24(14), 2539.
38. MC Donald LL., and Guyr, HD., 1970. Preliminary evaluation of new candiolate materials as toxicants, repellent and attracts against stored product insect marketing. *Res.* 1970, 189p

39. Mele, M.O.G., 2007. Inventaire des insectes des stocks de riz au Bénin: estimation des Pertes occasionnées, Mémoire de licence à l'Université d'Abomey-Calavi, Bénin 72p
40. Nanfack, F. M., Dongmo, Y. Z., & Fogang, M. A. R. (2015). Les insectes impliqués dans les pertes post-récolte des céréales au Cameroun: méthodes actuelles de lutte et perspectives offertes par la transgénèse. *International Journal of Biological and Chemical Sciences*, 9(3), 1630-1643. (cameroun)
41. Noudogbessi, J.P., Keke M., Félicien, A., and Sohounhloue, D.C.K., 2009. Evaluation of the insecticidal, larvicidal and ovicidal effects on *callosobruchus maculatus* of essential oils of *Cymbopogon Giganteus* and of *Xylopi Aethiopica*. *Sci. Study Res.*, 10: 337-338
42. Ogendo J. O., Deng, AL., Belmain, SR., Walker, DJ., Musandu, AO., Obura, RK., 2004. Pest status of *Sitophilus zeamais* Motschulsky, control methods and constraints to safe maize grain storage in Western Kenya, Egerton. *Journal of Science and Technology* 5, 175-193
43. Oliveira, A.P., Santana, A.S., Santana, E.D., Lima, A.P.S., Faro, R.R., Nunes R.S., Lima, A.D., Blank, A.F., Araújo, A.P.A., Cristaldo, P.F., 2017. Nanoformulation prototype of the essential oil of *Lippia sidoides* and thymol to population management of *Sitophilus zeamais* (Coleoptera: Curculionidae) *Ind. Crop. Prod.* 2017 ;107 :198–205. doi: 10.1016/j.indcrop.2017.05.046.
44. Panthenius, C.U., 1988. “Etat des pertes dans les systèmes de stockages du maïs au niveau des petits paysans dans la région maritime au Togo,” Fiche technique 83, GTZ, 1988.
45. Paranagama, P., Abeysekera, T., Nugaliyadde, L., Abeywickrama, K., 2003. Effects of the essential oils of *Cymbopogon citratus*, *C. nardus* and *Cinnamomum zeylancium* on pest incidence and grain quality of rough rice (paddy) stored in an enclosed seed box, *Journal of Food Agriculture and Environment* 134,134-13
46. Phasomkusolsil, S., and Soonwera, M., 2011. “Efficacy of herbal essential oils as insecticide against *Aedes aegypti* (Linn.), *Culex quinquefasciatus*(Say) and *Anopheles Dirus* (Peyton and Harrison),” *Southeast Asian Journal of Tropical Medicine and Public Health*, vol. 42, no. 5, pp. 1083–1092, 2011.
47. Phillips, T.W., Throne, J.E., 2010. Biorational approaches to managing stored-product insects. *Annu. Rev. Èntomol.* 2010; 55:375–397. doi: 10.1146/annurev.ento.54.110807.090451.

48. Philogène, B. J. R., Regnault-Roger, C., Vincent, C., 2008. Biopesticides d'origine végétale : bilan et perspectives, 1-24P. In Regnault-Roger, c., Philogène, B.JR., Vincent, C. (éds) *Biopesticides d'origine végétale*, 2ème éd., Lavoisier, Paris.
49. Regnault-Roger, C., 2002. De nouveaux phyto-insecticides pour le troisième millénaire. In: Philogène B.J.R, Regnault-Roger C. et Vincent C., coord. *Biopesticide d'origine végétale*. Paris: Lavoisier-Editions Tec et Doc, 19-39 p.
50. Renoz, F., Demeter, S., Degand, H., Nicolis, S. C., Lebbe, O., Martin, H., ... & Hance, T. (2022). The modes of action of *Mentha arvensis* essential oil on the granary weevil *Sitophilus granarius* revealed by a label-free quantitative proteomic analysis. *Journal of Pest Science*, 95(1), 381-395.
51. Rösch, P., Popp, J., and Raman, K.W., 1996. Investigations on lamiaceae. J. Molecular Structure, 121: 480-481.
52. Saedi, N., et Crawford, G. H., 2006. "Botanical briefs: ylang-ylang oil-extracts from the tree *Cananga odorata*," *Cutis*, vol. 77, no. 3, pp. 149-150, 2006.
53. SARWAR, M., 2015. Protecting dried fruits and vegetables against insect pests invasions during drying and storage. *American Journal of Marketing Research* 1(3), 142-149.
54. Seck, D., (1991). Etude de l'infestation initiale de *Sitotroga cerealella* Oliv. (Lepidoptera, Gelechiidae) en fonction de la localisation des champs de mil, *Pennisetum typhoides* (L) Leeke. *International Journal of Tropical Insect Science*, 12(5-6), 503-509. doi:10.1017/S1742758400012959
55. Seri-Kouassi, P.B., Kanko, C., Aboua, N.L.R., Bekon, A.K., and Glitho, I.A., 2004. Action des huiles essentielles de deux plantes aromatiques de Coted'Ivoire sur *Callosobruchus maculatus* Fab. Du niebe. *C.R. Chimie*, 7: 1043-1046.
56. Shaya, E., Kostjukovski, M., Eilberg, J., Sukprakarn, C., 1997. Plant oil as fumigant and contact insecticides for the control of stored product insects. *Journal of Stored Products Research* 33, 7-15.
57. Soonwera, M., and Phasomkusolsil, S., 2014. "Mosquito repellent from Thai essential oils against dengue fever mosquito (*Aedes aegypti* (L.)) and filarial mosquito vector (*Culex quinquefasciatus* (Say)),” *African Journal of Microbiology Research*, vol. 8, no. 17, pp. 1819–1824, 2014.
58. Soonwera, M., and Phasomkusolsil, S., 2015. "Efficacy of Thai herbal essential oils as green repellent against mosquito vectors,” *Acta Tropica*, vol. 142, pp. 127–130, 2015.

59. Swigar, A.A., and Silverstein, R.M., 1981. Monoterpènes. Infrared. Mass. NMR Spectra and Kovats Indices. Aldrich Chem. Co. Milwaukee. WI. US
60. Thiam, Abdoulaye; Talla Gueye, Momar; Sanghare, Cheikhna Hamala Sangharé, Papa Seyni Cissokho , Elhadji Barka Ndiaye , Serigne Mbacké Diop, Michel Barka Diop , Ibrahima Ndiaye, Marie Laure Fauconnier , 2021.Characterization by GC/MS-FID and GC/MS-HS-SPME and Insecticidal activity against *Callosobruchus maculatus* (Fabricius, 1775) of essential oils and powder of *Xylopi aethiopica* (Dunal) A. Rich from Senegal• In Journal of Plant Protection Research, 61 (3), p. 203-212
61. Togola, A., Nwilene, F. E., Chougourou, D. C., & Agunbiade, T. (2010). Présence, populations et dégâts de l'alcute des céréales *Sitotroga cerealella* (Olivier)(Lepidoptera, Gelechiidae) sur les stocks de riz au Bénin. Cahiers Agricultures, 19(3), 205-209.
62. Vincent, C., Hallman, G., Panneton, B., Fleurat-Lessard, F., 2003. Management of Agricultural Insects with Physical Control Methods ». Annual Review of Entomology 48, 261 281.
63. Vincent, C., Panneton, B., Fleurat-Lessard, F., 2000. La lutte physique en phytoprotection. INRA, Paris. 347 141 p.
64. Werrie, P. Y., Durenne, B., Delaplace, P., & Fauconnier, M. L. (2020). Phytotoxicity of essential oils: Opportunities and constraints for the development of biopesticides. A review. *Foods*, 9(9), 1291.
65. Zettler J., Arthur F.H., 2000. Chemical control of stored product insects with fumigants and residual treatments. Crop. Prot. 2000 ;19 :577–582. doi: 10.1016/S0261-2194(00)00075-2.