Towards the optimization of botanical insecticides research: Aedes aegypti larvicidal natural products in French Guiana

Michaël Falkowski, Arnaud Jahn-Oyac, Guillaume Odonne, Claudiane Flora, Yannick Estevez, Seindé Touré, Isabelle Boulogne, Jean-Charles Robinson, Didier Béreau, Philippe Petit, et al.

Manuscript Details

Manuscript number ACTROP_2019_796_R1

Title Towards the optimization of botanical insecticides research: Aedes aegypti larvicidal natural products in French Guiana

Article type Research Paper

Abstract

Natural products have proven to be an immeasurable source of bioactive compounds. The exceptional biodiversity encountered in Amazonia, alongside a rich entomofauna and frequent interactions with various herbivores is the crucible of a promising chemodiversity. This prompted us to search for novel botanical insecticides in French Guiana. As this French overseas department faces severe issues linked to insects, notably the strong incidence of vector-borne infectious diseases, we decided to focus our research on products able to control the mosquito Aedes aegypti. We tested 452 extracts obtained from 85 species originating from 36 botanical families and collected in contrasted environments against an Aedes aegypti laboratory strain susceptible to all insecticides, and a natural population resistant to both pyrethroid and organophosphate insecticides collected in Cayenne for the most active of them. 8 species (Maytenus oblongata Reissek, Celastraceae; Costus erythrothyrsus Loes., Costaceae; Humiria balsamifera Aubl., Humiriaceae; Sextonia rubra (Mez) van der Werff, Lauraceae; Piper hispidum Sw., Piperaceae; Laetia procera (Poepp.) Eichl., Salicaceae; Matayba arborescens (Aubl.) Radlk., Sapindaceae; and Cupania scrobitulata Rich., Sapindaceae) led to extracts exhibiting more than 50% larval mortality after 48h of exposition at 100 µg/mL against the natural population and were considered active. Selectivity and phytochemistry of these extracts were therefore investigated and discussed, and some active compounds highlighted. Multivariate analysis highlighted that solvents, plant tissues, plant family and location had a significant effect on mortality while light, available resources and vegetation type did not. Through this case study we highlighted that plant defensive chemistry mechanisms are crucial while searching for novel insecticidal products.

Keywords Mosquito larvicides; Culicidae; Amazonian chemodiversity; screening optimization; quasi-Poisson generalized linear model; chemical defense

Corresponding Author Emeline Houel

Corresponding Author's Institution CNRS - UMR Ecofog 8172

Order of Authors Michaël Falkowski, Arnaud Jahn-Oyac, Guillaume Odonne, Claudiane Flora, Yannick Estevez, Seindé Touré, Isabelle Boulogne, jean-charles robinson, Didier Béreau, Philippe Petit, Didier Azam, Maïra Coke, Jean Issaly, Pascal Gaborit, Didier Stien, veronique Eparvier, Isabelle Dusfour, Emeline Houel

Suggested reviewers John Arnason, Murray Isman, Charles Cantrell

Submission Files Included in this PDF

File Name [File Type]

Acta_Trop__Insecticides_French_Guiana_letter_rev.docx [Cover Letter]

Response_reviewer_ActaTrop.docx [Response to Reviewers]

Falkowski_Botanical insecticides_Acta_Trop_highlights.docx [Highlights]

Falkowski_Botanical insecticides_Acta_Trop_graph_abstract.pdf [Graphical Abstract]

Falkowski_Botanical insecticides_Acta_Trop_revised_clean.docx [Manuscript File]

Falkowski_Botanical insecticides_SI_Acta_Trop.docx [Table]

declaration-of-competing-interests.docx [Conflict of Interest]

Emeline Houël, PhD
CNRS - UMR ECOFOG
Institut Pasteur de la Guyane
23 avenue Pasteur - BP6010
97306 Cayenne cedex
emeline.houel@ecofog.gf

Cayenne, August 23th, 2019

Dear Editor,

Please find attached the revised version of the manuscript now entitled "Towards the optimization of botanical insecticides research: *Aedes aegypti* larvicidal natural products in French Guiana" for consideration as a research article in *Acta Tropica*. This manuscript now has an abstract of 254 words; a main text of 5634 words from introduction to conclusion section; 90 references; 5 tables and 2 figures. Please also find attached 2 tables and 1 figure of supporting information. All of the co-authors have read this manuscript and have agreed to its content and conclusions.

Alongside you will find a file including the point-by-point response to the reviewers. We thank them and he editor for their valuable suggestions and addressed their remarks as carefully as possible to improve our manuscript and make it suitable for publication in *Acta Tropica*.

We hope that you will find it worthwhile for publication and look forward to hearing from you.

On behalf of the authors,

Dr Emeline Houël

Michaël Falkowski

Arnaud Jahn-Oyac

Guillaume Odonne

Claudiane Flora

Yannick Estevez

Seindé Touré

Isabelle Boulogne

Jean-Charles Robinson

Didier Béreau

Philippe Petit

Didier Azam

Maïra Coke

Jean Issaly

Pascal Gaborit

Didier Stien

Véronique Eparvier

Isabelle Dusfour

Dear Editor,

We thank you and the 3 reviewers for the positive comments and valuable suggestions that helped us to improve our manuscript. You will find herewith a revised version that addresses editor's and reviewers' questions, comments and suggestions. We provide our replies below (in blue).

Comments from the editors and reviewers:
- Editor

- Nice work, well conceived and presented!

The authors warmly thank the editor for having taken the time to review the manuscript and for this very positive comment.

In addition to the corrections required by reviewers please consider the following points:

- Title: according to its aim, Acta Tropica does not welcome case studies and reports. Please use a more appealing title, may I suggest something like: "Towards the optimization of botanical insecticides research: Aedes aegypti larvicidal natural products in French Guiana"? Feel free to rework as you prefer.

The title was modified as suggested.

- Avoid using keywords (e.g. Aedes aegypti) already in the title: this is not suitable for indexing purposes.

Keywords were modified as follows: "Mosquito larvicides; Culicidae; Amazonian chemodiversity; screening optimization; quasi-Poisson generalized linear model; chemical defense" instead of "Botanical insecticides; *Aedes aegypti*; larvicidal; French Guiana; quasi-Poisson generalized linear model; chemical defense" (lines 58-59)

- Please add Highlights and a Graphical Abstract. This would boost the appeal of this work.

Highlights and a Graphical Abstract were added as suggested. The designer of the graphical abstract was added in the acknowledgments section.

- Line 526: add publication year here!

Done.

- I noted that Rev. 1 suggested to cite a very recent review on Acta Tropica (Pavela et al. 2019) covering more than 400 plants extracts and also focused on botanical insecticide development in the real-world, where I am also coauthor. I should agree with his/her suggestion since this review really fits well the topic of your study. On the other hand, since I am a coauthor of it, I want to clearly highlight that you are not forced in any way to cite it. I just hope you find it of interest for your knowledge; then consider it for improving your references in this occasion if you feel it can add something to the theoretical background of the study.

We added the suggested reference in the introduction (lines 67-70). This reference was also mentioned in the text (lines 289-290; 451; 461) to provide complementary discussion elements.

An article cited in the suggested reference (Pavela et al., 2015) was also added to improve the manuscript (lines 298-299).

We sincerely thank Reviewer 1 and the Editor for this suggestion. Some members of the team indeed currently work on a novel project concerning the development of larvicidal formulations based on *Sextonia rubra* wood extract, identified as promising in the presented work. The objective is to deepen the results obtained in the laboratory concerning the crude extract and isolated compounds. We hope to progress towards the development of a marketable product through semi-operational bioassays and the investigation of the mode of action and eco- and cytotoxicity. Therefore we found in the suggested reference many considerations and articles that will be more than useful for this new project.

Again, thanks for submitting this nice work to Acta Tropica.

Thank you again for having taken the time to review this manuscript, and for these encouraging comments!

- **Reviewer 1**

- In this work authors tested 452 extracts obtained from 85 species growing in French Guiana against different strains of Aedes aegypti (both susceptible and resistant to pyrethroid and organophosphate insecticides). They found out that some extracts exhibited more than 50% mortality at 100 ppm. Furthermore, they determined cytotoxicity and non-target effects of plant extracts. Although, this work is well written and scientifically sound, I found some areas that need improvement. Please see the comments below.

The authors thank Reviewer 1 for the positive comments. Responses to the questions and suggestions are presented below.

- Only the extract of Costus erythrothyrsus was chemically characterized by column chromatography and NMR. Why only this one? What about the other active extracts? For instance, authors did not analyze the extract from Piper hispidum and they justified that with the fact that Piper species have been much investigated so far. In my opinion, this is not enough. For Sextonia rubra authors limited to cite some references rather than performing chemical analysis. I suggest to chemically characterize the most active extracts.

The phytochemical analysis of *C. erythrothyrsus* extract was indeed initially the only one presented integrally (materials & methods and results) in this article. However some other phytochemical studies were performed during the project, even if some choices were made and did not allow us to fully characterize all the active extracts. In particular, we chose to work more intensely on two species, *M. oblongata* and *S. rubra*. The authors therefore hope that the following comments and modification will increase the clarity of the text concerning this point, and answer Reviewer 1 questions and suggestions.

Concerning *L. procera* bark extract, preliminary phytochemical studies were performed but were unfortunately inconclusive. This information was added in the text as follows (lines 437-439): "Preliminary phytochemical studies were performed but did not lead to a clear conclusion concerning the pure compounds responsible for the bioactivity of the extract." and the last sentence of the paragraph modified (lines 439-441): "It would thus be interesting to pursue the evaluation of the larvicidal activity of the pure compounds, and correlate *L. procera* bark extracts chemical profiles and larvicidal activity for example through a metabolomic approach."

M. oblongata extract bioguided fractionation was performed by our team in the context of the same project. This work having been published earlier in the *Journal of Natural Products* (Touré et al. 2017) due to the important amount of NMR data to be displayed, only the reference of this article was cited here.
The full extract and active compounds characterization having indeed been performed in the context of the same project, we added the following sentence to clarify this point (lines 448-451): "Whereas published elsewhere, this work was performed by our team in the context of the same project, as bioguided fractionation of active extracts is indeed a key step to progress towards the development of novel botanical insecticides (Isman and Grieneisen, 2014; Pavela 2015; Pavela et al. 2019)."

Concerning the choices we made (for example not further studying *H. balsamifera* and *P. hispidum* extracts, which were not the most active in our hands), the following sentence was added (lines 459-465):
"Moreover, if the potential development of a novel botanical insecticide is logically based on its biological activity and its selectivity, other criteria such as the availability of the resource are also fundamental when it comes to valorization (Borges et al. 2019; Pavela et al., 2019). We therefore chose to concentrate on *S. rubra* extract, the most active extract but also the 4th species exploited in the forest industry in French Guiana, leading to wood wastes that could represent a source of valuable material and undisclosed as larvicidal product before the work of our team."

Concerning *S. rubra*, it was indeed not clear which part of the cited work was performed by our team in the context of the project and which was only external literature. The text was therefore modified as follows:

Lines 466-467: "*Sextonia rubra* (Mez) Van der Werff (Lauraceae) wood and bark extracts were actually shown to possess excellent larvicidal activities in the context of this study."

Lines 473-476: "As part of the cited work was performed by member of our team, we were able to characterize the chemical composition of the larvicidal extract and confirm the presence of the two γ-lactones rubrenolide and rubrynolide according to the previously described protocols, to characterize the chemical composition of the larvicidal extract and confirm the presence of the two γ-lactones rubrenolide and rubrynolide."

Lines 476-477: "We also highlighted during this project the strong larvicidal activity of these two compounds against *Ae. aegypti*"

To clarify this point, the Material and Methods section was modified in point 2.6. (lines 223-262) to give more technical details, or indicate references to the work concerning chemical characterization and published elsewhere by our team.

- Introduction: Insert a paragraph dealing with the vector, Aedes aegypti, on which they assayed the plant extracts.

Some information and references were added in the introduction concerning *Ae. aegypti* (lines 81-88).

- You may consider to cite in Introduction this important review on plant extracts as mosquito larvicides: Acta Tropica 2019, 193, 236-271; in this review some very active (LC50 < 10 ppm) plant extracts against mosquito larvae have been reported and described in detail.

The reference to the review was added in the introduction. For a more detailed response please refer to the editor's comments section above.

- It is not clear the aim of the work at the bottom of Introduction.
The presented study had as principal aim to discover novel botanical insecticides from the Amazonian biodiversity. In this context we also 1/ wanted to investigate the link between plants chemical defense and insecticidal properties 2/ discuss some methodological issues, both points aiming at optimizing plant screening protocols.
Some modifications were done in the introduction (lines 110-118) in an attempt to improve its clarity, according to Reviewer 1 and Reviewer 3 suggestions (for Reviewer 3 see further comments below):

"The objective was to consider plants having various growth-defense trade-offs in order to potentially improve our capacity to discover insecticidal compounds, and investigate ecological trends governing insecticidal properties. This approach has been inspired by the concept of "human chemical defenses" presented by Berenbaum (Berenbaum 1995). Literature-based chemotaxonomy was also included as a criterion for plant selection in our search for novel larvicidal extracts and compounds. As a consequence of the project, some methodological issues had to be discussed considering the huge amount of scientific literature already dealing with botanical insecticides research (Isman and Grieneisen 2014). The present contribution therefore also addresses some of these issues through illustrative examples encountered along the study, in an attempt to optimize plant screening for natural insecticides discovery.

- Sect. 2.3.: replace LD50 with LC50.
The modification was done throughout the text.

- Table 2 : Insert the LC50/90 values for the most active extracts.
To remain consistent with the mortality values given after 48h of exposition, LC_{50} values calculated at 48h for the active extracts (extracts exhibiting larvicidal activities ≥ 50% against Cayenne resistant strain and highlighted in bold characters in Table 2) were inserted in Table 2.

- Table 3: Report the IC50 values on KB and MRC5 cells.
The test performed on KB and MRC5 cells were only performed at the two concentrations indicated in the table (10 µg/ml and 1 µg/ml) for each extract. It therefore does not allow us to calculate an IC50. At this stage of the project, as cytotoxicity was only used as a tool to restrain the screening to the most promising extracts in terms of activity and selectivity, the measured values were sufficient to fulfill this aim. But we agree to the fact that the complete characterization of the extract and compounds through IC50 measurement is an important step, and this will be performed for *S. rubra* in the context of the ongoing above-mentioned project.

- Only 3 out of 8 active plant extracts were assayed on non-target organisms. What about the remaining ones?
In the context of the reported project we only had the opportunity to test 3 extracts. During the novel ongoing project concerning *S. rubra* and already mentioned above, we will assess the crude extract and pure compounds ecotoxicity, as well as the bioactivity of formulations on non-target organisms. More results will therefore be available at the end of this second project.

- It is unlikely that the active compounds of *Costus erythrothyrsus* extract are fatty acids. I suggest to analyze further this extract in order to highlight some bioactive compounds. Otherwise, I suggest to assay the identified fatty acids in order to confirm authors' hypothesis.
As described in the manuscript (lines 407-408): “In the case of this extract, bioguided fractionation allowed us to isolate an active mixture of 3 fatty acids.” So to our knowledge these compounds reasonably seems linked to the larvicidal activity, which is also consistent with the existing literature (Harada et al. 2000; Rahuman et al. 2008; Ramsewak et al. 2001; Santos et al. 2017). However, we agree with Reviewer1 concerning the fact that further studies would be of great interest, in particular due to the variability observed concerning *C. erythrothyrsus* extracts activity, and some of them were indeed discussed by our team. However, as we unfortunately do not have any more of the active fraction available in the laboratory, and as we chose to further investigate *S. rubra* wood extrat as explained above, these studies would be the object of a future work. To underline this point the following sentence was added in the text: “Further studies to investigate these mechanisms and the compounds responsible for the biological activity would thus be of great interest.” (lines 406-407).

- **Reviewer 2**

- Accept.

The authors thank Reviewer 2 for having reviewed and accepted the submitted work.

- **Reviewer 3**

- While this manuscript basically reports a screening study of crude plant extracts, its' value is enhanced because (i) extracts are tested against both insecticide-susceptible and –resistant populations; (ii) extracts are tested against indicator non-target aquatic organisms to determine ecotoxicity; (iii) extracts are tested against two human cell lines to assess general cytotoxicity; and (iv) a very large number of extracts from a wide range of plant taxa are evaluated. The inclusion of deltamethrin and extracts of *Muellera* as positive controls is applauded, although these were only tested against the mosquito larvae and not against the non-targets nor the cell cultures. I didn't see any reference to permethrin effects on the mosquitoes in the Results and Discussion section, although I may have missed it.

The authors are grateful to Reviewer 3 for the comments and suggestions.

Concerning the use of insecticide-resistant mosquito populations, a sentence was rephrased in the abstract (lines 43-44 of the revised manuscript): we added "for the most active of them" at the end of the sentence as the text was not completely clear about the number of extracts tested against the insecticide-resistant population.

Other points:

1. Why were the *Sextonia* extracts included in Table 3 if they were not tested? This seems strange.

Thank you for this comment, it is indeed not logical. The lines corresponding to S. rubra extracts were deleted from the table. As the cytotoxicity of these extracts will be further evaluated in a currently ongoing project, a sentence was added in the text (Lines 490-492): "This point will <u>thus</u> be further evaluated <u>in the context of an ongoing project which aims at deepening the above-described results regarding the crude extract and isolated compounds and progressing towards the development of a marketable product</u>."

The beginning of the sentence was also rephrased as asked (see the last point of the responses to reviewers): "Complementary results <u>have also been</u> published, <u>which highlighted</u> notable toxicity for rubrenolide against several human cancer cell lines (Tofoli et al. 2016).

2. The pairwise comparisons between plant parts and between extracting solvents is logical and useful, but I don't see the value in the comparisons between pairs of plant families.

Our objective through the multivariate analysis was to evaluate the importance of several parameters considering the larvicidal activity. The chosen factors were as well related to the extraction method (solvents) as to plant collection criteria. As these criteria were based both on chemical defense concerns and on chemotaxonomy, pairwise comparisons between plant families were also included. To clarify this point the word "chemotaxonomic" was added in the Material and Methods section (point 2.7, line 271): “to relate mortality responses to the technical, chemotaxonomic and environmental predictor variables.”

3. The paragraph starting on line 78 seems a bit ecologically gratuitous to me. It would be much simpler to say that plant biodiversity is highest in the tropics, and especially in Amazonia (with a reference), and that herbivore and pathogen selection pressure on plants is probably highest in the tropics as well (with a reference).

In this paragraph we described the various biotic and abiotic parameters which lead to modifications of the growth/defense trade-offs concerning resource allocations to explain why we chose to collect various plant parts coming from ecologically contrasted environments and different vegetation types. However, the link between this paragraph and the following could indeed be better explained. To clarify this point the following paragraph was modified as follows (lines 108-113):

“For a few years, our team has therefore built a collection of plant extracts from ecologically contrasted Amazonian environments, including long-lasting trees and herbaceous plants, extracted from different plant organs. The objective was to consider plants having various growth-defense trade-offs in order to potentially improve our capacity to discover insecticidal compounds, and attempt to investigate ecological trends governing insecticidal properties.”

But I believe that the logic between natural plant chemical defense and the search for natural insecticides is flawed. Why? When we screen plants, we are searching for exceptions to the rule, i.e., plant natural products that are acutely toxic to insects. This is searching for needles in a haystack, for the simple reason that the *modus operandi* for plants in nature is to discourage herbivory (or fungal infection) – either behaviorally or physiologically, rather than to kill the challenger outright. Yet the latter is what humans attempt to do when using chemicals (natural or otherwise) to manage pest populations. How many botanical pest control products work strictly as feeding/oviposition deterrents or as larval growth inhibitors? None that I know of.

Thank you for this interesting comment! This is a complex subject that could be intensively discussed. Indeed, and even if the authors globally agree with the rather exceptional presence of acutely toxic substances for insects in plants, this discussion may also be replaced in a Darwinian perspective. As far as there is no determinism in plant-insect coevolution, finding highly insecticidal substances remains in fact probable, as what gives extra fitness to an individual tends to be selected positively as far as the cost is not exaggerated. In particular, the publication written by Doyle McKey (Am. Nat. 1974) about the adaptive patterns in alkaloid physiology highlight many points of great interest concerning this subject and the defensive role of these highly toxic compounds, also presenting other biological characteristics (bitter taste in case of herbivory, feeding stimulant for some species…).

As an extensive discussion about this point was to our opinion difficult to integrate in the article, we however added the following sentence in the conclusion to highlight this point to the readers (lines 581-583): “Moreover, we also exemplified that plant defensive chemistry mechanisms are crucial while trying to discover insecticidal products, even if the search for toxic compounds only encompasses a small facet of this highly complex machinery."

4. Line 373: "It can be assumed that defense compounds were produced by the plant on this occasion." I think this is a pretty big assumption. It is a possibility, but there are other reasons why this particular sample was bioactive. I don't think you can make this claim without some supporting chemistry from your sample.

Thank you for this comment. This part of the sentence was modified as follows, and the end of the paragraph modified according to this comment and a suggestion made by Reviewer 1:

Lines 405-407: "Defense compounds may have been produced by the plant on this occasion, and further studies to investigate these mechanisms and the compounds responsible for the biological activity would thus be of great interest."

Lines 418-419: "Therefore the fact that a single extract was found active might be correlated with the activation of defense mechanisms in response to herbivory damage and this observation could be the subject of complementary studies."

5. Line 438: "Complementary results…" This is an incomplete sentence. Please rewrite it.

This sentence was rephrased (now line 488): "Complementary results have also been published, which highlighted notable toxicity for rubrenolide against several human cancer cell lines (Tofoli et al. 2016)."

Highlights

- French Guiana biodiversity was explored for the search of novel botanical insecticidal products
- 452 extracts from 85 plant species were tested for larvicidal activity against *Aedes aegypti*
- Bioassays included both insecticide-susceptible and -resistant *Ae. aegypti* populations

Sextonia rubra wood extract and its main components were highlighted as promising products

- Correlations between extracts larvicidal activity and plants chemical defense were investigated

Graphical abstract

Towards the optimization of botanical insecticides research: *Aedes aegypti* larvicidal natural products in French Guiana

Michaël Falkowski[a], Arnaud Jahn-Oyac[a], Guillaume Odonne[b], Claudiane Flora[a], Yannick Estevez[a], Seindé Touré[a,c], Isabelle Boulogne[a,d,e], Jean-Charles Robinson[f], Didier Béreau[f], Philippe Petit[d], Didier Azam[g], Maïra Coke[g], Jean Issaly[h], Pascal Gaborit[h], Didier Stien[i], Véronique Eparvier[c], Isabelle Dusfour[h,j,*], Emeline Houël[a*]

[a] CNRS, UMR EcoFoG, AgroParisTech, Cirad, INRA, Université des Antilles, Université de Guyane, 97300 Cayenne, France.

[2] Laboratoire Ecologie, Evolution, Interactions des Systèmes Amazoniens (LEEISA), CNRS, Université de Guyane, IFREMER, 97300 Cayenne, France.

[c] CNRS, Institut de Chimie des Substances Naturelles, UPR2301, Université Paris Saclay, 91198 Gif-sur-Yvette, France.

[d] Université des Antilles, Campus de Fouillole, 97157 Pointe-à-Pitre Cedex, Guadeloupe, France.

[e] Université de ROUEN, UFR des Sciences et Techniques, Laboratoire Glycobiologie et Matrice Extracellulaire Végétale, UPRES-EA 4358, Fédération de Recherche « Normandie Végétal » FED 4277, 76821, Mont-Saint-Aignan, France.

[f] Université de Guyane, Laboratoire COVAPAM, UMR QualiSud, Campus universitaire de Troubiran, BP 792, 97337 Cayenne cedex, France.

[g] Unité Expérimentale d'Ecologie et d'Ecotoxicologie Aquatique, INRA-U3E, 35042 Rennes, France.

[h] Institut Pasteur de la Guyane, Vectopôle Amazonien Emile Abonnenc, Unité Contrôle et Adaptation des vecteurs, 23 avenue Pasteur, BP6010, 97306 Cayenne cedex, France.

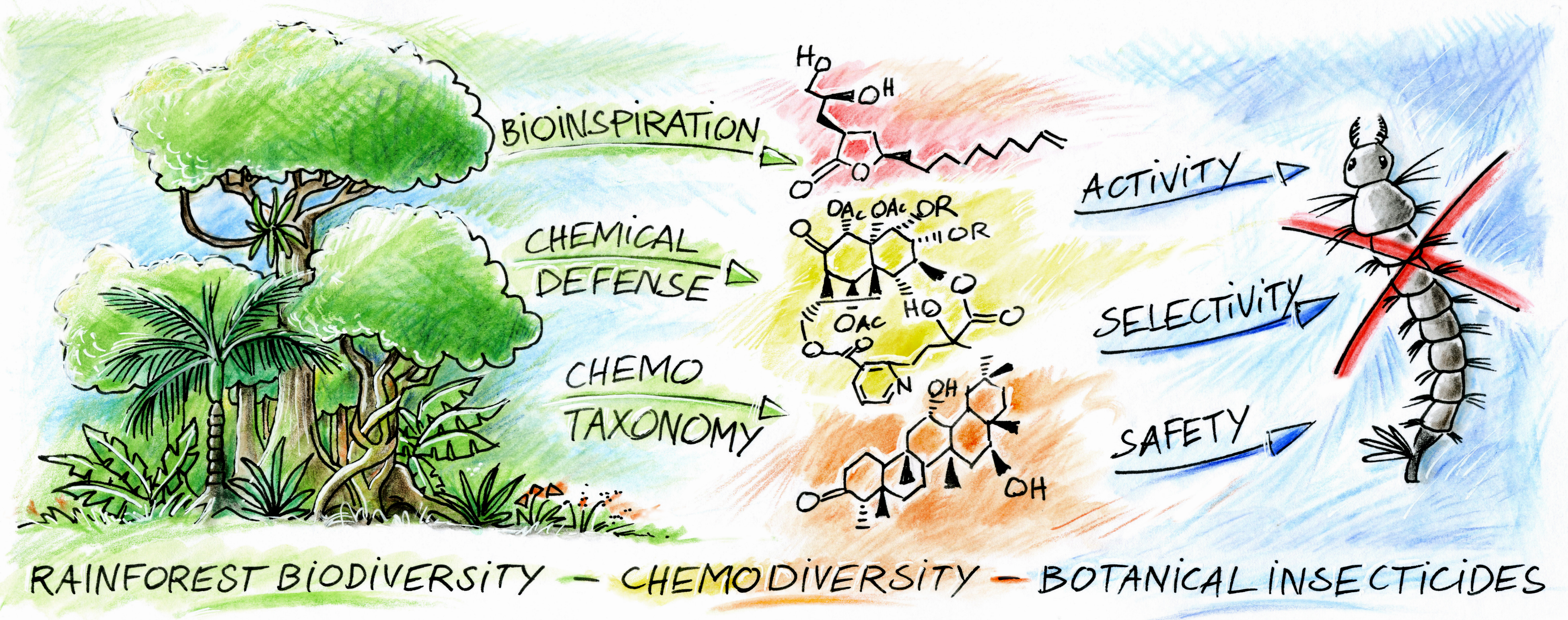
[i] Sorbonne Université, CNRS, Laboratoire de Biodiversité et Biotechnologie Microbienne, LBBM, Observatoire Océanologique, 66650 Banyuls-sur-mer, France.

[j] INRS-Institut Armand Frappier, Groupe recherche en écologie microbienne, 531 boulevard des prairies, H7V 1B7, Laval, QC, Canada,

* Correspondence to: Emeline Houël, CNRS, UMR EcoFoG, AgroParisTech, Cirad, INRA, Université des Antilles, Université de Guyane, 97300 Cayenne, France ; Tel.: +594 594 29 31 34 e-mail address: emeline.houel@ecofog.gf, ORCID 0000-0003-4888-2332 and Isabelle Dusfour, INRS-Institut Armand Frappier, Groupe recherche en écologie microbienne, 531 boulevard des prairies, H7V 1B7, Laval, QC, Canada, isabelle.dusfour@pasteur.fr

Summary

French Guiana biodiversity was explored for the search of novel larvicidal products against both insecticide-susceptible and -resistant *Aedes aegypti* populations.


BIOINSPIRATION
CHEMICAL DEFENSE
CHEMO TAXONOMY
ACTIVITY
SELECTIVITY
SAFETY
RAINFOREST BIODIVERSITY – CHEMODIVERSITY – BOTANICAL INSECTICIDES

Towards the optimization of botanical insecticides research: *Aedes aegypti* larvicidal natural products in French Guiana

Michaël Falkowski[a], Arnaud Jahn-Oyac[a], Guillaume Odonne[b], Claudiane Flora[a], Yannick Estevez[a], Seindé Touré[a,c], Isabelle Boulogne[a,d,e], Jean-Charles Robinson[f], Didier Béreau[f], Philippe Petit[d], Didier Azam[g], Maïra Coke[g], Jean Issaly[h], Pascal Gaborit[h], Didier Stien[i], Véronique Eparvier[c], Isabelle Dusfour[h,j,*], Emeline Houël[a*]

[a] CNRS, UMR EcoFoG, AgroParisTech, Cirad, INRA, Université des Antilles, Université de Guyane, 97300 Cayenne, France.

[2] Laboratoire Ecologie, Evolution, Interactions des Systèmes Amazoniens (LEEISA), CNRS, Université de Guyane, IFREMER, 97300 Cayenne, France.

[c] CNRS, Institut de Chimie des Substances Naturelles, UPR2301, Université Paris Saclay, 91198 Gif-sur-Yvette, France.

[d] Université des Antilles, Campus de Fouillole, 97157 Pointe-à-Pitre Cedex, Guadeloupe, France.

[e] Université de ROUEN, UFR des Sciences et Techniques, Laboratoire Glycobiologie et Matrice Extracellulaire Végétale, UPRES-EA 4358, Fédération de Recherche « Normandie Végétal » FED 4277, 76821, Mont-Saint-Aignan, France.

[f] Université de Guyane, Laboratoire COVAPAM, UMR QualiSud, Campus universitaire de Troubiran, BP 792, 97337 Cayenne cedex, France.

[g] Unité Expérimentale d'Ecologie et d'Ecotoxicologie Aquatique, INRA-U3E, 35042 Rennes, France.

[h] Institut Pasteur de la Guyane, Vectopôle Amazonien Emile Abonnenc, Unité Contrôle et Adaptation des vecteurs, 23 avenue Pasteur, BP6010, 97306 Cayenne cedex, France.

[i] Sorbonne Université, CNRS, Laboratoire de Biodiversité et Biotechnologie Microbienne, LBBM, Observatoire Océanologique, 66650 Banyuls-sur-mer, France.

[j] INRS-Institut Armand Frappier, Groupe recherche en écologie microbienne, 531 boulevard des prairies, H7V 1B7, Laval, QC, Canada,

* Correspondence to: Emeline Houël, CNRS, UMR EcoFoG, AgroParisTech, Cirad, INRA, Université des Antilles, Université de Guyane, 97300 Cayenne, France ; Tel.: +594 594 29 31 34 e-mail address: emeline.houel@ecofog.gf, ORCID 0000-0003-4888-2332 and Isabelle Dusfour, INRS-Institut Armand Frappier, Groupe recherche en écologie microbienne, 531 boulevard des prairies, H7V 1B7, Laval, QC, Canada, isabelle.dusfour@pasteur.fr

Abstract

Natural products have proven to be an immeasurable source of bioactive compounds. The exceptional biodiversity encountered in Amazonia, alongside a rich entomofauna and frequent interactions with various herbivores is the crucible of a promising chemodiversity. This prompted us to search for novel botanical insecticides in French Guiana. As this French overseas department faces severe issues linked to insects, notably the strong incidence of vector-borne infectious diseases, we decided to focus our research on products able to control the mosquito *Aedes aegypti*. We tested 452 extracts obtained from 85 species originating from 36 botanical families and collected in contrasted environments against an *Aedes aegypti* laboratory strain susceptible to all insecticides, and a natural population resistant to both pyrethroid and organophosphate insecticides collected in Cayenne for the most active of them. 8 species (*Maytenus oblongata* Reissek, Celastraceae; *Costus erythrothyrsus* Loes., Costaceae; *Humiria balsamifera* Aubl., Humiriaceae; *Sextonia rubra* (Mez) van der Werff, Lauraceae; *Piper hispidum* Sw., Piperaceae; *Laetia procera* (Poepp.) Eichl., Salicaceae; *Matayba arborescens* (Aubl.) Radlk., Sapindaceae; and *Cupania scrobitulata* Rich., Sapindaceae) led to extracts exhibiting more than 50% larval mortality after 48h of exposition at 100 µg/mL against the natural population and were considered active. Selectivity and phytochemistry of these extracts were therefore investigated and discussed, and some active compounds highlighted. Multivariate analysis highlighted that solvents, plant tissues, plant family and location had a significant effect on mortality while light, available resources and vegetation type did not. Through this case study we highlighted that plant defensive chemistry mechanisms are crucial while searching for novel insecticidal products.

Keywords

Mosquito larvicides; Culicidae; Amazonian chemodiversity; screening optimization; quasi-Poisson generalized linear model; chemical defense

1. Introduction

Although botanical insecticides are at the origin of all insecticidal compounds, they have been laid or put aside by the agrochemical industry. However due to the great damages caused by the overuse of synthetic compounds, natural products and molecules obtained from plants are again considered suitable pest control alternatives (George et al. 2014; Gerwick and Sparks 2014; Isman 2015). The considerable needs, efforts, challenges and limitations of this research are in particular described in a recent review, also presenting a wide range of plant extracts tested for larvicidal activity against various mosquitoes (Pavela et al., 2019).

Intensification of research on natural insecticides is in particular due to the crucial need of effective products to control mosquito vectors of pathogens, particularly viruses and *Plasmodium* parasites (Benelli 2015; Benelli and Mehlhorn 2016). Indeed during last years, the world has regularly experienced the emergence or re-emergence of arthropod-borne viruses such as yellow fever, dengue, chikungunya, and more recently Zika viruses. As vector control remains an important, if not the sole tool to fight diseases spread, this increasing number of outbreaks alongside the expansion of insecticide resistance urge the development of novel molecules to control invasive mosquito populations such as *Aedes aegypti* (L., 1762) and *Aedes albopictus* (Skuse, 1895) (Carvalho and Moreira 2017; Fauci and Morens 2016; Faucon et al. 2015; Higgs and Vanlandingham 2015; Moyes et al. 2017). In particular *Ae. aegypti* Linnaeus (Diptera: Culicidae) is a cosmopolitan species originating from Africa but now well-established in all tropical and subtropical regions. This mostly diurnal anthropophilic mosquito is foud in urban communities and surrounding area, its presence being favoured by the existence of artificial breeding sites such as used tires, water tanks or flower pots. Its opportunistic behavior, high adaptation ability and biological characteristic such as eggs resistant to dessication, alongside with trade globalization and rapid urbanization are some keys of this species' ecological success (Carvalho and Moreira 2017; Simmons et al., 2012; Abilio et al., 2018). As sessile organisms, plants must have developed a wide range of secondary metabolites as defense compounds against predators and pests during their evolution (Agrawal and Weber 2015; Fraenkel 1959). The exceptional biodiversity of plants, entomofauna and herbivores in the tropics leads to a promising chemodiversity, due to the constant and dynamic interactions between plants and their environment (Becerra 2007; Ehrlich and Raven 1964; Richards et al.2015). Some factors were highlighted for playing a major role in the effectiveness of defense. According to the optimal defense theory, the allocation of defense chemicals is driven by the predation pressure exercised on a given plant organ, and the fitness value of this organ for the plant (McCall and Fordyce 2010; McKey 1974). Besides, not only this fitness value but also resources from a given environment would drive both the type and the amount of secondary metabolites (Coley et al. 1985; Endara and Coley, 2011). Open environments also represent places of higher herbivorous insects' abundance, and therefore larger insects-plants interactions, which could lead to the production of more, and/or more diverse insecticidal compounds (Lamarre et al. 2012). The type of defense may also differ between plants. Long-living, slow-growing species including woody plants would allocate resources to highly concentrated quantitative defenses such as polyphenols and tannins, while short-lived species, e.g. herbaceous plants, would synthetize smaller amount of low molecular weight toxic compounds such as alkaloids, phenolic compounds or cyanogenic glycosides (Feeny 1976; Rhoades and Cates 1976; Smilanich et al. 2016).

For a few years, our team has therefore built a collection of plant extracts from ecologically contrasted Amazonian environments, including long-lasting trees and herbaceous plants, extracted from different plant organs. The objective was to consider plants having various growth-defense trade-offs in order to potentially improve our capacity to discover insecticidal compounds, and investigate ecological trends governing insecticidal properties. This approach has been inspired by the concept of “human chemical defenses” presented by Berenbaum (Berenbaum 1995). Literature-based chemotaxonomy was also included as a criterion for plant selection in our search for novel larvicidal extracts and compounds. As a consequence of the project, some methodological issues had to be discussed considering the huge amount of scientific literature already dealing with botanical insecticides research (Isman and Grieneisen 2014). The present contribution therefore also addresses some of these issues through illustrative examples encountered along the study, in an attempt to optimize plant screening for natural insecticides discovery.

2. Materials and methods

2.1. Plant material

All plant species (Table 1) were collected in French Guiana. They are not protected species and their collection was allowed without restriction at the concerned locations. Collection authorizations were given by the ONF (National Forest Office) where necessary. Herbarium vouchers were deposited in French Guiana Herbarium (CAY) where specialists confirmed botanical identification. All collection data are available at: http://publish.plantnet-project.org/project/caypub.

Botanical families	Plant species	CAY	Location [a]	Plant part
Annonaceae	*Anaxagorea dolichocarpa* Sprague & Sandwith	Odonne 721	Ko	Leaves, stems
	Guatteria ouregou (Aubl.) Dunal	Odonne 718	Ko	Leaves, stems
	Xylopia cayennensis Maas	Odonne 788	Ma	Leaves, bark
	Xylopia frutescens var. *ferruginea* R.E. Fr.	Odonne 774	Ma	Leaves, stems, bark
Apocynaceae	*Tabernaemontana siphilitica* (L.f.) Leeuwenb.	Odonne 724	Ko	Aerial parts
	Lacmellea aculeata (Ducke) Monach.	Odonne 749	Si	Leaves, stems
Asteraceae	*Bidens cynapiifolia* Kunth	Odonne 760	Mc	Whole plant
Bignoniaceae	*Handroanthus capitatus* (Bureau & K. Schum.) Mattos	Odonne 795	Rg	Leaves, stems
	Adenocalymma moringifolium (DC.) L.G.Lohmann	Odonne 727	Ko	Aerial parts
Boraginaceae	*Varronia schomburgkii* (DC.) Borhidi	Odonne 789	Ma	Aerial parts
Celastraceae	*Maytenus oblongata* Reissek	Odonne 726	Ko	Leaves, stems
	Maytenus sp.	Odonne 797	Rg	Leaves and fruits, stems
Chrysobalanaceae	*Couepia bracteosa* Benth.	Odonne 775	Ma	Leaves, stems
	Licania affinis Fritsch	Odonne 716	Ko	Leaves, stems
Clusiaceae	*Clusia palmicida* Rich.	Odonne 798	Rg	Leaves, stems
Combretaceae	*Terminalia amazonia* (J.F. Gmel.) Exell	Odonne 783	Ma	Leaves, bark
Convolvulaceae	*Ipomoea leprieurii* D.F. Austin	Odonne 791	Rg	Aerial parts
Costaceae	*Costus erythrothyrsus* Loes.	Odonne 742	Si	Leaves, stems, inflorescence
	Costus cf *spiralis* (Jacq.) Roscoe	Houël 3	Rm	Inflorescence
	Costus spiralis var. *villosus* Maas	Houël 4	Ko	Inflorescence
	Costus spiralis var. *villosus* Maas	Houël 5	Ro	Inflorescence
Cyperaceae	*Scleria cyperina* Willd. ex Kunth	Odonne 793	Rg	Aerial parts

Dilleniaceae	*Tetracera asperula* Miq.	Odonne 781	Ma	Leaves, fruits
Euphorbiaceae	*Cnidoscolus urens* (L.) Arthur	Odonne 790	Mc	Aerial parts
	Conceveiba guianensis Aubl.	Odonne 722	Ko	Leaves, stems
	Croton guianensis Aubl.	Odonne 786	Ma	Leaves
	Croton macradenis Görts & Punt	Eparvier 202	Mo	Aerial parts
	Croton matourensis Aubl.	Eparvier 167	Mt	Leaves, bark
	Croton nuntians Croizat	Eparvier 199	Si	Leaves, stems
	Croton nuntians Croizat	Odonne 743	Si	Leaves, stems
	Sapium argutum (Müll. Arg.) Huber	Odonne 794	Rg	Leaves, stems
Fabaceae	*Alexa wachenheimii* Benoist	Odonne 719	Ko	Leaves, bark
	Bocoa prouacensis Aubl.	238 [b]	Si	Bark
	Chamaecrista desvauxii var. *saxatilis* (Amshoff) H.S. Irwin & Barneby	Odonne 806	Rg	Aerial parts
	Chamaecrista diphylla (L.) Greene	Odonne 758	Mc	Aerial parts
	Dalbergia monetaria L.f.	Odonne 762	Mc	Leaves, stems
	Desmodium barbatum (L.) Benth.	Odonne 746	Si	Whole plant
	Dimorphandra polyandra Benoist	Odonne 779	Ma	Leaves, bark
	Entada polystachya (L.) DC.	Odonne 759	Mc	Leaves, stems
	Enterolobium schomburgkii (Benth.) Benth.	Forget 4976	Si	Wood, bark
	Inga alba (Sw.) Willd.	Moretti 1129	Si	Wood
	Inga virgultosa (Vahl) Desv.	Odonne 805	Rg	Leaves, stems
	Muellera frutescens (Aubl.) Standl.	Eparvier 108B	Mo	Leaves
	Macrolobium bifolium (Aubl.) Pers.	Odonne 725	Ko	Leaves, stems
	Macrolobium guianense (Aubl.) Pulle	Odonne 785	Ma	Leaves, wood

	Ormosia coutinhoi Ducke	Odonne 717	Ko	Leaves, stems
	Senna quinquangulata (Rich.) H.S. Irwin & Barneby	Odonne 738	Si	Leaves, stems
	Spirotropis longifolia (DC.) Baill.	Eparvier 137	Si	Wood, bark, roots
	Stylosanthes guianensis (Aubl.) Sw.	Odonne 792	Rg	Aerial parts
	Swartzia guianensis (Aubl.) Urb.	Odonne 715	Ko	Leaves, stems
	Vigna luteola (Jacq.) Benth.	Odonne 764	Mc	Aerial parts
Humiriaceae	*Humiria balsamifera* Aubl.	Eparvier 101	Mc	Wood
	Humiria balsamifera Aubl.	Odonne 784	Ma	Bark
Lauraceae	*Licaria cannella* (Meisn.) Kosterm.	Silland 16	Rg	Wood
	Sextonia rubra (Mez) van der Werff	1039 [b]	Si	Bark
	Sextonia rubra (Mez) van der Werff	Rodrigues 12	Rg	Wood
Loranthaceae	*Phthirusa* sp.	Odonne 720	Ko	Leaves, stems
Lythraceae	*Cuphea blackii* Lourteig	Odonne 796	Rg	Aerial parts
Malpighiaceae	*Byrsonima aerugo* Sagot	Odonne 780	Ma	Leaves
	Byrsonima crassifolia (L.) Kunth	Odonne 755	Mc	Leaves, bark
	Byrsonima spicata (Cav.) DC.	Odonne 754	Mc	Leaves, wood, bark
Malvaceae	*Eriotheca surinamensis* (Uittien) A. Robyns	Odonne 801	Rg	Leaves
	Sterculia pruriens (Aubl.) K. Schum	1058 [b]	Si	Bark
Melastomataceae	*Ernestia granvillei* Wurdack	Odonne 804	Rg	Aerial parts
Meliaceae	*Azadirachta indica* A. Juss	Odonne 712	Ko	Leaves
	Guarea guidonia (L.) Sleumer	Odonne 756	Mc	Leaves, stems
Moraceae	*Bagassa guianensis* Aubl.	n.i. [c]	Si	Bark
Myrtaceae	*Myrcia saxatilis* (Amshoff) McVaugh	Odonne 799	Rg	Leaves, stems
Orobanchaceae	*Anisantherina hispidula* (Mart.) Pennell	Odonne 757	Mc	Whole plant

Piperaceae	*Piper hispidum* Sw.	Odonne 741	Si	Leaves, stems
Polygalaceae	*Polygala longicaulis* Kunth	Odonne 787	Ma	Whole plant
Rubiaceae	*Posoqueria longiflora* Aubl.	Odonne 723	Ko	Leaves
	Tocoyena guianensis K. Schum.	Odonne 802	Rg	Aerial parts
	Sipanea pratensis Aubl.	Odonne 803	Rg	Aerial parts
Salicaceae	*Banara guianensis* Aubl.	Odonne 748	Si	Leaves, stems
	Casearia grandiflora Cambess.	Odonne 777	Ma	Leaves, wood, bark
	Laetia procera (Poepp.) Eichl.	1003 [b]	Si	Bark
	Laetia procera (Poepp.) Eichl.	424 [b]	Si	Bark
	Laetia procera (Poepp.) Eichl.	Odonne 771	Mc	Bark
Sapindaceae	*Cupania scrobiculata* Rich.	Odonne 778	Ma	Leaves, stems, fruits
	Matayba arborescens (Aubl.) Radlk.	Odonne 776	Ma	Leaves, stems, fruits
	Paullinia sp.	Odonne 713	Si	Leaves, stems
	Paullinia pinnata L.	Odonne 763	Mc	Aerial parts
Sapotaceae	*Manilkara huberi* (Ducke) A. Chevalier	Riéra 1904	Si	Wood, bark
Simaroubaceae	*Quassia amara* L..	Odonne 714	Rm	Stems
Siparunaceae	*Siparuna guianensis* Aubl.	Odonne 747	Si	Leaves, stems
Solanaceae	*Cestrum latifolium* Lam.	Odonne 761	Mc	Leaves, stems
	Solanum leucocarpon Dunal	Odonne 740	Si	Leaves, stems
	Solanum stramoniifolium Jacq.	Odonne 751	Si	Aerial parts
	Solanum subinerme Jacq.	Odonne 752	Si	Aerial parts
Vochysiaceae	*Erisma uncinatum* Warm.	514 [b]	Si	Bark

[a] Legend: Régina (Rg), Roura (Ro), Matoury (Mt), Rémire-Montjoly (Rm), Montsinéry-Tonnegrande (Mo), Macouria (Mc), Kourou (Ko), Sinnamary (Si), Mana (Ma)

[b] Trees from a permanent plot (St Elie) in Sinnamary. This permanent research plot hosts up to 800 identified trees. The systematic identification of the trees was performed at the IRD herbarium in Cayenne where a voucher sample is deposited

[c] Not integrated in Cayenne herbarium. Bagassa guianensis was collected in the framework of other research projects and botanical identification was made in situ by professional forest workers

Table 1 Botanical families, plant species, voucher number (Cayenne herbarium - CAY), location and plant parts collected for testing against 3rd-4th instar larvae of *Ae. aegypti* L. (Diptera: Culicidae)

Plants were collected along an E/W geographical gradient (Figure 1) in the following locations: Régina (Rg), Roura (Ro), Matoury (Mt), Rémire-Montjoly (Rm), Montsinéry-Tonnegrande (Mo), Macouria (Mc), Kourou (Ko), Sinnamary (Si), Mana (Mn). The various environment types were the following: *terra firme* forest, forest edges, white-sand forest, river bank, dry savannah, coastline, inselberg and ruderal/disturbed areas. To perform multivariate analysis, these environments were described according to the available light (few light: forest, to strong light: open environment such as savannah or inselberg) and resources (from poor environment such as inselbergs to abundant resources environment such as forest or river bank) at the collection place. The type of vegetation (life-forms) was also characterized (temporary vegetation, secondary / low or slightly ligneous vegetation, ligneous species, large trees). Collected plant organs were: bark, wood, stems, roots, leaves, aerial parts, whole plant, inflorescence and fruits depending on the plant.

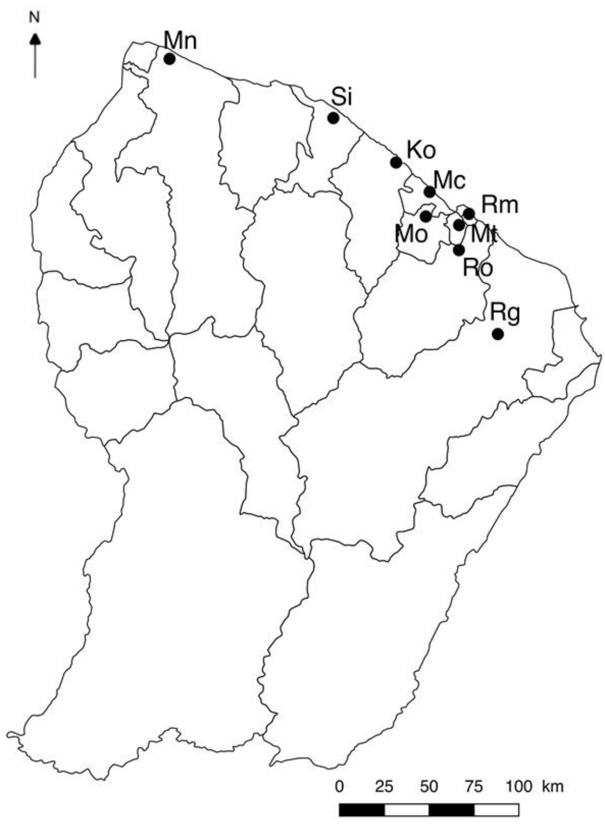


Fig. 1 Repartition of the collection localities. Legend: Régina (Rg), Roura (Ro), Matoury (Mt), Rémire-Montjoly (Rm), Montsinéry-Tonnegrande (Mo), Macouria (Mc), Kourou (Ko), Sinnamary (Si), Mana (Ma)

2.2. Extraction

All plant parts were air-dried (room temperature, 10% air relative humidity) and finely ground into powder prior to extraction. Plant powders (30 g) were successively extracted at room temperature by maceration during 24h under stirring, using either ethyl acetate (3 x 150 ml) followed by methanol (1 x 150 ml), or petroleum ether (3 x 150 ml) followed by boiling water (1 x 150 ml). After each extraction, the solution was filtered and the solvent removed by evaporation under reduced pressure with a SpeedVac™ concentrator (Savant SPD121P, Thermo Scientific). The resulting crude extracts (up to 4 extracts for each plant part of each species) were stored in a freezer at -18°C until assayed.

2.3. Evaluation of larvicidal activity

Insect collection and rearing, cup assay and data analysis were performed as previously described (Touré et al. 2017). Two *Aedes aegypti* (Diptera: Culicidae) strains were used for testing the extracts and compounds. The laboratory strain Paea, collected in French Polynesia, and maintained for a decade in the insectary at the Institut Pasteur de la Guyane, French Guiana, is susceptible to all insecticides. The Cayenne natural population is resistant to both pyrethroid and organophosphate insecticides and is a first generation (F1) strain reared from wild-caught larvae (F0) (Dusfour et al. 2011). The choice to perform a two-step screening was based on the recommendations made by Cos et al. for antimicrobial screening to develop a stronger proof of concept (Cos et al. 2006). Indeed LC_{50} could increase 100 times in *Ae. aegypti* resistant populations compared to susceptible ones (Lima et al. 2011). Late third or early fourth-instar larvae were used in the tests. All extracts were investigated using the WHO procedure for testing of mosquito larvicides (WHO 2005). For each bioassay, 25 larvae of each strain were transferred to cups containing 99 mL of distilled water and 1 mL of the tested product diluted in ethanol, at the suitable concentration, and four cups, representing a total of 100 larvae, were used for each tested concentration. For the determination of mortality rates, the final concentration was 100 µg/mL and for LC_{50} calculation, concentrations leading from 0 to 100% mortality were tested. Larval mortality was recorded 24 and 48 h after exposure. Control treatments were performed for each test with 1 mL of ethanol, and deltamethrin (0.05 µg/mL) was used as a positive control in the case of the laboratory strain Paea. *Muellera frutescens* (Aubl.) Standl. (Fabaceae), of which leaves were previously described to contain the rotenoid compounds rotenone, tephrosin and deguelin, and to be toxic against *Ae. aegypti* mosquito larvae, was included in the screening to serve as a botanical positive control in order to validate the test protocol (Falkowski et al. 2016; Nirma et al. 2009). Abbott's formula was applied to mortalities if mortality in the control was between 5% and 20% (Abbott 1925). The test was invalidated if mortality in the control was greater than 20%. Lethal doses were obtained by a probit regression under a general linearized model [BioRssay 6.1. script in R environment version 3.2.0 (https://www.r-project.org/)].

2.4. Cytotoxicity assays

Cytotoxicity assays were conducted with KB (nasopharyngeal epidermoid carcinoma) and MRC5 (normal lung tissue of a 14-week-old male foetus) cell lines using the procedure described by Tempête et al. (Tempête et al. 1995). Docetaxel was used as positive control.

2.5. Ecotoxicological assessment on non-target species, Daphnia magna *and* Chironomus riparius

Ecotoxicity assays were adapted from the guidelines of the "Immediate Immobilization Test" (OECD No. 202) for *Daphnia magna* (Straus, 1820) and the "Immediate Immobilization Test" (OECD No. 235) for *Chironomus riparius* (Meigen, 1804). The extracts were tested only at the LC_{50} value defined from the *Ae. aegypti* Paea strain sensitivity for each extract. Three conditions were tested: control, control/solvent, and LC_{50}, with four replicates per condition. The physicochemical measurements (pH, dissolved oxygen, conductivity) were performed with measuring devices (sensors). The remaining measures (chlorine, nitrites, nitrates, phosphates) were performed with aquarium strips. Photoperiod and temperature were recorded using a "templight" recorder throughout the test period, from clutch incubation until the end of the exposure.

2.6. Phytochemical studies

2.6.1. General remarks

^{1}H NMR spectra were recorded at 400 MHz and ^{13}C NMR spectra at 100.6 MHz on a Varian 400 MR spectrometer equipped with a 5 mm inverse probe (Auto X PGF 1H/15N-13C). Samples were dissolved in deuterated chloroform ($CDCl_3$) in 5 mm tubes as stated. Chemical shifts are in ppm downfield from tetramethylsilane (TMS), and coupling constants (*J*) are in Hz (s stands for singlet, d for doublet, t for triplet, q for quartet, m for merduplet, br for broad). TLC analyses were performed using ALUGRAM®SIL G/UV_{254} plates, eluted with petroleum ether 90:10 and revealed using a solution of 1% $KMnO_4$ in water.

Water (HPLC grade) was obtained from a Milli-Q system (Milli-Q plus, Millipore Bedford, MA). HPLC analyses were performed on a Discovery C18 column (15 cm x 4.6 mm, 5 µm, Supelco) at 1 mL/min using a Waters HPLC system equipped with a W2996 photodiode array absorbance detector and a W2424 light-scattering detector. HPLC semi-preparative chromatography was performed at 15 mL/min on a Discovery C18 column (15 cm x 21.2 mm, 5 µm, Supelco) using a Waters HPLC system equipped with a W600 pump and a W2487 double wavelength UV detector (Waters).

2.6.2. Costus erythrothyrsus *Loes. (Costaceae) phytochemical study*

C. erythrothyrsus inflorescence ethyl acetate extract was purified by column chromatography using a petroleum ether / ethyl acetate gradient from 100:0 to 10:90 and eventually 100% methanol. Ten fractions were gathered according to their TLC profile. Fraction F4 eluted with petroleum ether / ethyl acetate 85:15 exhibited 72% larvicidal mortality against *Ae. aegypti* Paea laboratory strain at 100 µg/mL and 100% larvicidal mortality against Cayenne resistant strain at the same concentration, and its chemical composition was therefore investigated using NMR. TLC profiles from the crude extract and fraction F4 were also compared to standard lipids L13-0521 (VHOSO, Very High Oleic Sunflower Oil fatty acids), L13-0001 (Linseed oil fatty acids including 50% linolenic acid, 21% linoleic acid and 13% oleic acid), E12-1986 (stearic acid), L14-0146 (hydrogenated VHOSO methylic ester – stearic acid) and P14-002 (VHOSO methylic ester – oleic acid) kindly provided by ITERG (Institut des Corps Gras, Pessac, France).

2.6.3. Maytenus oblongata *Reissek (Celastraceae) phytochemical study*

The thoroughgoing bioguided fractionation as well as isolation and identification of *M. oblongata* extract components were described in Touré et al. (2017).

2.6.4. Sextonia rubra *(Mez.) van der Werff (Lauraceae) phytochemical study*

Isolation of rubrenolide and rubrynolide was performed using HPLC semi-preparative chromatography according to previously described procedures (Fu et *al.* 2019) and their identification confirmed by NMR.

2.7. *Multivariate analysis*

The complete set of data used for multivariate analysis is available in Supporting Information (table S1). Multivariate analysis was conducted in R 3.2.0 environment. Z-scores were obtained from mortality data. This transformation gives the dataset a mean of 0 and a standard deviation of 1. A generalized linear model (GLM) using the quasi-Poisson distribution, logistic link function and a mixture of forwards and backwards selection was used to relate mortality responses to the technical, chemotaxonomic and environmental predictor variables. Pairwise comparisons were further performed with TukeyHSD test between modalities of each factor that were identified to have an effect on mortalities. Family, solvent, organ, light, resource, type of vegetation and location were thus selected as explanatory variables in our analyses.

3. Results and discussion

3.1. *Larvicidal screening on susceptible and resistant Ae. aegypti strains*

A total of 144 plant parts issued from 85 species belonging to 36 botanical families were collected during the project (Table 1). Fabaceae (24%) were the most represented, with 17 genera and 20 species. Euphorbiaceae, Annonaceae, Sapindaceae and Solanaceae represented from 5 to 8% of the collected species (Figure 2). The genera *Byrsonima*, *Croton* and *Solanum* were the most represented, with 3 to 4 species each. For two species (*Croton nuntians* Croizat, Euphorbiaceae, *Laetia procera* (Poepp.) Eichler, Salicaceae) 2 to 3 different samples of the same plant part were collected at different times and locations. It should be noticed that the Fabaceae family is one of the most cited in the literature for its insecticidal activity, being notably a source of rotenoids and in particular rotenone, a well-known, yet controversial botanical insecticide (Boulogne et al. 2012; Isman 2006; Pavela et al., 2019).

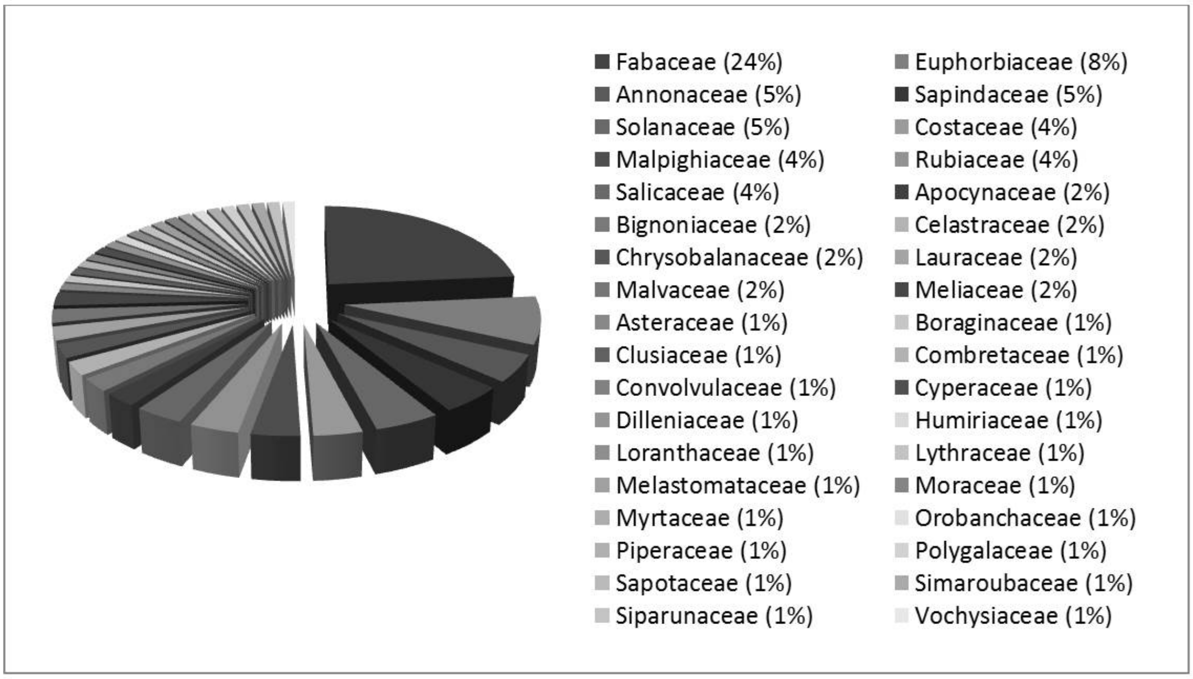


Fig. 2 Diversity of the collected species: the relative importance of the botanical families is shown in the pie chart (families are represented clockwise in the pie chart)

Eventually, 452 extracts were obtained and tested on *Ae. aegypti* Paea strain. The complete dataset is available in Supporting Information (Table S1). The extracts exhibiting more than 50% mortality after 48 h of exposition at 100 µg/mL were considered active, which is consistent with the requirements proposed by Pavela (2015). Fifteen botanical species thus led to 22 larvicidal extracts listed in Table 2. The active extracts on the Paea strain were then tested on a natural population of resistant Cayenne *Ae. aegypti* in order to obtain more selective and realistic results, thus improving the probability to highlight promising plant extracts for the search of new botanical insecticides.

The extracts exhibiting larvicidal mortality ≥ 50% after 48 h of exposition at 100 µg/mL against this resistant strain are highlighted in Table 2. Eventually, 8 species led to 11 larvicidal extracts against the Cayenne strain. Among the botanical families hosting these active species Celastraceae (Alvarenga and Ferro 2005; Deepa and Narmatha Bai 2010), Lauraceae (Cuca-Suarez et al. 2012; Dias and Moraes, 2014), Piperaceae (Dorla et al. 2017; Lija-Escaline and al. 2015; Marques and Kaplan 2015), and Sapindaceae (Diaz and Rossini 2012), are particularly well described for their numerous insecticidal effects. These 8 species represents 9% of the collected species and 2% of the extracts. By comparison, among 94 extracts from 10 Brazilian plant species selected randomly or according to chemotaxonomic criteria,19 were considered to be effective against *Ae. aegypti* larvae, exhibiting LC_{50} < 250 µg/mL, including 6 (6.4%) extracts with LC_{50} < 100 µg/mL (Oliveira et al. 2010). Another 27 species identified from a screening performed on 83 Asteraceae belonging to 48 genera, promoted statistically significant mortality of *Ae. fluviatilis* (Lutz, 1904) 4^{th} instar larvae, with 8 (9.6%) species leading to 50% or more mortality at 100 µg/mL (Macêdo et al. 1997). In terms of active extracts, these results are consistent with those observed in our screening, even if contrary to the example of the Asteraceae family, the selected plants in our case did not all belong to botanical families well-known for the insecticidal activities of their species. This could be an indication that selecting species on different criteria, e.g. the ecosystem, could also lead to interesting results.

Botanical families	Plant species [a]	Plant part	Solvent [c]	Extraction yield (%)	Mortality (%, Paea strain) ± SD	LC_{50} (µg/ml), Paea strain [d]	Mortality (%, Cayenne strain) ± SD [e]	LC_{50} (µg/ml), Cayenne strain [d]
Annonaceae	*Xylopia frutescens var. ferruginea*	Leaves	PE	3.0	54 ± 6.6		4 ± 0.0	
Asteraceae	*Bidens cynapiifolia*	Whole plant	EA	1.4	97 ± 1.0		5 ± 3.0	
Celastracee	***Maytenus oblongata***	**Stems**	**EA**	**1.5**	**98 ± 1.1**	**74.4 ± 2.5 [f]**	**91 ± 3.0**	**n.t.**
Chrysobalanaceae	*Licania affinis*	Leaves	PE	0.8	97 ± 1.1		2 ± 1.1	
	Licania affinis	Stems	PE	0.1	100 ± 0.0		n.t.	
Costaceae	***Costus erythrothyrsus (Odonne 742)***	**Inflorescence**	**EA**	**4.8**	**100 ± 0.0**	**45.0 (95%CI: 36.6-54.0)**	**100 ± 0.0**	**55.7 (95%CI: 49.8-61.2)**
	Costus erythrothyrsus (Odonne 742)	**Inflorescence**	**PE**	**3.9**	**97 ± 1.0**	**n.t.**	**99 ± 1.0**	**n.t.**
Euphorbiaceae	*Croton macradenis*	Aerial parts	PE	0.4	54 ± 3.8		5 ± 1.9	
Fabaceae	*Alexa wachenheimii*	Bark	PE	0.2	56 ± 2.8		2 ± 1.1	
	Muellera frutescens [b]	Leaves	PE	3.7	100 ± 0.0		n.t.	
	Muellera frutescens	Leaves	EA	4.3	100 ± 0.0		n.t.	
	Muellera frutescens	Leaves	M	4.6	97 ± 1.9		n.t.	
Humiriaceae	***Humiria balsamifera (Odonne 784)***	**Bark**	**EA**	**17.9**	**84 ± 4.3**	**49.0 (95%CI 35.8-64.8)**	**91 ± 1.9**	**45.0 (CI95% 39.0-51.2)**
Lauraceae	***Sextonia rubra (Rodrigues 12)***	**Wood**	**EA**	**4.2**	**100.0 ± 0.0**	**3.1 7 (95%CI 2.7-3.7)**	**100.0 ± 0.0**	**n.t.**
	Sextonia rubra (1039)	**Bark**	**EA**	**2.4**	**100.0 ± 0.0**	**n.t.**	**85.0 ± 6.0**	**n.t.**
Piperaceae	***Piper hispidum***	**Leaves**	**EA**	**7.0**	**62 ± 5.3**	**54.7 (95%CI 46.0-64.0)**	**84 ± 1.6**	**n.t.**
Salicaceae	***Laetia procera (1003)***	**Bark**	**PE**	**3.4**	**94 ± 2.0**	**33.5 (95%CI 28.0-39.8)**	**87 ± 3.4**	**61.0 (95%CI 49.8-77.7)**
	Laetia procera (1003)	**Bark**	**EA**	**2.7**	**63 ± 6.0**	**43.7 (95%CI: 33.9-57.3)**	**57 ± 7.2**	**65.9 (95%CI: 51.7-90.5)**
Sapindaceae	***Matayba arborescens***	**Fruits**	**EA**	**11.2**	**60 ± 2.8**	**76.9 (95%CI 67.7-86.7)**	**98 ± 1.1**	**40.5 (95%CI 34.1-46.2)**
	Matayba arborescens	**Fruits**	**PE**	**17.4**	**51 ± 6.6**	**n.t.**	**50 ± 6.8**	**n.t.**
	Cupania scrobiculata	**Fruits**	**EA**	**2.9**	**64 ± 1.6**	**105.3 (95%CI 86.6-136.5)**	**74 ± 3.8**	**102.5 (95%CI 80.4-145.4)**
Solanaceae	*Cestrum latifolium*	Stems	EA	0.7	58 ± 10.5		7 ± 1.9	

[a] Voucher number at Cayenne Herbarium (CAY) or tree number from a permanent plot in Sinnamary is indicated when several samples were previously collected

[b] *Muellera frutescens* was used as a botanical insecticide positive control in order to validate the test protocol

[c] PE: petroleum ether; EA: ethyl acetate; M: methanol

[d] LC_{50} values were calculated after 48h of exposition unless otherwise specified

[e] n.t.: not tested.

[f] LC_{50} value was calculated after 24h of exposition using the protocol descred in Touré et al. (2017)

Table 2 Active extracts (mortality ≥ 50% after 48 h of exposition at 100 µg/mL) against *Ae. aegypti* Paea and Cayenne strains 3rd-4th instar larvae. Extracts exhibiting larvicidal activities ≥ 50% against Cayenne resistant strain are highlighted in bold characters.

3.2. Selectivity of the active extracts and phytochemical discussion

In the global perspective of improving our knowledge about the selectivity of the extract in terms of bioactivity, cytotoxicity of the extracts highlighted as active on the *Ae. aegypti* Cayenne strain was then evaluated on two human cellular strains (KB cancerous cell line, MRC5 healthy cell line). Concurrently 3 randomly selected extracts (*Maytenus oblongata* Reissek, Celastraceae, *Matayba arborescens* (Aubl.) Radlk., Sapindaceae, and *Humiria balsamifera* Aubl., Humiriaceae) were tested for possible ecotoxicity against non-target species *C. riparius*, an aquatic diptera, and *D. magna*, a small planktonic crustacean. If the obtained values (inhibition of cellular growth for cytotoxic assay, and mortality for ecotoxicity) were too high, the extract was abandoned. These bioassays were used at this step of the screening to prevent further study of active non-selective extracts. Indeed, as stated by Isman and Grieneisen, studying the effect of botanical insecticides on human health is quite rare in the existing literature, as most botanicals are renowned for their low acute toxicity (Isman and Grieneisen 2014). However, plants can be highly toxic too and this parameter should clearly be taken into account in the context of the search for new insecticides of plant origin. The cytotoxicity results are presented in Table 3. *Cupania scrobitulata* Rich. (Sapindaceae) fruits extract was cytotoxic and was dropped. *M. arborescens* fruits extract was only moderately cytotoxic but was strongly ecotoxic with almost 100% of mortality against both *C. riparius* and *D. magna* at 100 μg/mL and was therefore dropped as well.

H. balsamifera bark ethyl acetate extract exhibited significant cyto- and ecotoxicity, with respectively 52±2% and 40±5% of growth inhibition against KB and MRC5 cells at 10 μg/ml, and leading to almost 100% of mortality against both *C. riparius* and *D. magna* at 80 μg/mL. The latter value is close to the LC_{50} values of 63.6 (CI95% 52.7-77.5) and 49.0 (CI95% 35.8-64.8) μg/mL measured at 24 and 48 h against the laboratory strain Paea. *H. balsamifera* is a large tree common in Amazonia and North-East Brazil. Numerous compounds were isolated from this species, including *trans*-isolongifolenone (Da Silva et al. 2004).[48] Interestingly, a repulsive effect of this compound was described on *Ae. aegypti* and *Anopheles stephensi*, but also on other insects (Wang et al. 2013; Zhang et al. 2009). Moreover, t*rans*-isolongifolenone is described as odorless, whereas some of its derivatives have a characteristic woody smell (Zhang et al. 2009). It has to be noted that the sampled bark was strongly odoriferous, and we noticed in the field that this phenomenon was linked to a damage caused to the bark, leading to an abundant production of resinous product. It should therefore be checked if the more frequently encountered non-odoriferous barks also lead to larvicidal extracts, and if odoriferous isolongifolenone derivatives exhibit larvicidal activity. In the case of this extract, toxicity could be linked with the plant's response to stress due to mechanical damage, leading to the production of defensive compounds. If these molecules led to the discovery of a larvicidal extract, our results also highlight the fact that cyto- and ecotoxicity bioassays are essential in the evaluation of a potential new insecticidal product, as *H. balsamifera* bark extract showed to be non-selective against the various targets tested in our study. It should also be mentioned that *H. balsamifera* wood extract did not exhibit any larvicidal activity in our hands. It would be interesting to investigate if this difference is linked to the collected specimen or to a systematic difference in terms of chemical defenses allocation between the two tissues.

Botanical families	Plant species [a]	Plant part / Solvent [b]	Growth inhibition of KB cells, % ± SD [c]		Growth inhibition of MRC5 cells, % ± SD [c]	
			10 µg/ml	1 µg/ml	10 µg/ml	1 µg/ml
Celastracee	*Maytenus oblongata*	Stems (EA)	9±1	n.t.	8±6	n.t.
Costaceae	*Costus erythrothyrsus* (Odonne 742)	Inflorescence (EA)	0±1	0±10	0±1	0±1
Humiriaceae	*Humiria balsamifera* (Odonne 784)	Bark (EA)	52±2	5±2	40±5	18±4
Piperaceae	*Piper hispidum*	Leaves (EA)	22±5	0±1	0±4	0±1
Salicaceae	*Laetia procera* (1003)	Bark (PE)	18±2	0±1	45±5	4±1
Sapindaceae	*Matayba arborescens*	Fruits (EA)	24±6	n.t.	16±2	n.t.
	Cupania scrobiculata	Fruits (EA)	71±1	1±6	67±2	27±2

[a] Voucher number at Cayenne Herbarium (CAY) or tree number from a permanent plot in Sinnamary is indicated when several samples were previously collected

[b] PE: petroleum ether; EA: ethyl acetate; M: methanol

[c] PE: petroleum ether; EA: ethyl acetate; M: methanol

Table 3 Growth inhibition of KB (nasopharyngeal epidermoid carcinoma) and MRC5 (normal lung tissue of a 14-week-old male fetus) cell lines.

Positive control: docetaxel induced 0.0005% survival at 1 µg/mL.

Species from the genus *Costus* are rhizomatous perennial herbs from the Costaceae family (Specht and Stevenson 2006). In our study, *C. erythrothyrsus* Loes. inflorescence ethyl acetate extract exhibited no cytotoxicity against human cell lines, which could make this extract a valuable candidate in the search of new botanical insecticides. The LC_{50} at 24 and 48 h were 69.1 (95% CI: 59.4-82.9) and 45.0 (95% CI: 36.6-54.0) µg/mL, respectively, against the Paea strain. Although the insecticidal activity of several *Costus* species has been described before in the literature, neither *C. eryhthothyrsus* nor *Costus* inflorescences were described for insecticidal activity (Pipithsangchan and Morallo-Rejesus 2005; Surendra Kumar et al. 2014). However, although the first extract exhibited strong larvicidal activity, no other positive result could be observed while testing inflorescences extracts from the same *C. erythrothyrsus* specimen at a later collection date, or inflorescences collected from other *Costus* species. Interestingly, we noticed that the first collected inflorescence had been damaged by some predators. Defense compounds may have been produced by the plant on this occasion, and further studies to investigate these mechanisms and the compounds responsible for the biological activity would thus be of great interest. In the case of this extract, bioguided fractionation allowed us to isolate an active mixture of 3 fatty acids. ^{1}H NMR spectrum was consistent with a mixture linolenic, linoleic and oleic acids (Figure S1) (Sacchi et al. 1997). This type of compounds were already found in a chemical analysis performed on the inflorescence of *Etlingera elatior* Jack, a plant from the Zingiberaceae family, which is in close relationship with Costaceae, and are known for their larvicidal activity (Harada et al. 2000; Jeevani Osadee Wijekoon et al. 2011; Rahuman et al. 2008; Ramsewak et al. 2001; Santos et al. 2017). Moreover, they were also highlighted for their role in chemical defense mechanisms, and more particularly induced defense against pathogenous organisms (Domingues et al. 2007; Rojas et al. 2014; Ryu et al. 2005). Therefore the fact that a single extract was found active might be correlated with the activation of defense mechanisms in response to herbivory damage and this observation could be the subject of complementary studies.

The case of *L. procera* petroleum ether bark extract also raised interesting questions concerning the activation of chemical defense mechanisms and the interest of studying several samples of a same species. *L. procera* is a long-lived pioneer tree, i.e., a fast-growing light-demanding species, characterized as an early colonizer of the Amazonian forest (Santos et al. 2012). Petroleum ether bark extract of *L. procera* N°1003 collected in the Saint Elie permanent investigation plot in Sinnamary (Si) led to a LC_{50} value of 33.5 (CI95% 28.0-39.8) µg/mL at 48 h against the laboratory strain Paea. However, no larvicidal activity was discovered while testing two other bark extracts. One inactive tree bark had been collected in the same mature forest area as the active bark (tree N°424), and the second one in a secondary forest close to dry savannahs in Macouria (Mc). Therefore, the activity described for the first sample could be due again to an increased production of toxic compounds by a single individual rather than an environmental effect of resources availability. Indeed, Jullian et al. already described the fact that bark extracts from the same tree N°1003, collected a few years before, led to the isolation of laetiaprocerine A and laetianolide A as major compounds, whereas casearlucine A and caseamembrol A were the main components of tree N°424 bark extract, alongside with small amounts of laetiaprocerine A and laetianolide A (Jullian et al. 2005). Preliminary phytochemical studies were performed but did not lead to a clear conclusion concerning the pure compounds responsible for the bioactivity of the extract. It would thus be interesting to pursue the evaluation of the larvicidal activity of the pure compounds, and correlate *L. procera* bark extracts chemical profiles and larvicidal activity for example through a metabolomic approach.

M. oblongata extracts were not cytotoxic against KB and MCR5 human cell lines at 10 µg/mL, and exhibited noticeable toxicity against *C. riparius* whereas it did not have any activity against *D. magna* at 75 µg/mL, as presented in a previously published article (Touré et al. 2017). This article also reported the isolation in *M. oblongata* extract of two new sesquiterpene alkaloids with a β-dihydroagrofuran skeleton and exhibiting significant activity against Paea strain *Ae. aegypti* larvae. Whereas published elsewhere, this work was performed by our team in the context of the same project, as bioguided fractionation of active extracts is indeed a key step to progress towards the development of novel botanical insecticides (Isman and Grieneisen, 2014; Pavela 2015; Pavela et al. 2019).

During the screening, *Piper hispidum* Sw. (Piperaceae) leaves ethyl acetate extract was also identified as active, with LC_{50} values of 70.5 (CI95% 60.4-81.6) and 54.7 (CI95% 45.9-64.0) µg/mL at 24 and 48 h against the laboratory strain Paea. However, due to the vast amount of existing literature on insecticidal Piperaceae and compounds isolated from *Piper* species such as piperine or dillapiole,[42-44] we did not investigate further the chemical composition of this extract (Dorla et al. 2017; Lija-Escaline and al. 2015; Marques and Kaplan 2015). Moreover, if the potential development of a novel botanical insecticide is logically based on its biological activity and its selectivity, other criteria such as the availability of the resource are also fundamental when it comes to valorization (Borges et al. 2019; Pavela et al., 2019). We therefore chose to concentrate on *S. rubra* extract, the most active extract but also the 4th species exploited in the forest industry in French Guiana, leading to wood wastes that could represent a source of valuable material and undisclosed as larvicidal product before the work of our team.

Sextonia rubra (Mez) Van der Werff (Lauraceae) wood and bark extracts were actually shown to possess excellent larvicidal activities in the context of this study. *S. rubra* is a neotropical shade-tolerant rainforest tree species native to South America, and one of the most commercially exploited wood for construction in French Guiana owing to its excellent natural durability. Two compounds rubrynolide and rubrenolide were first isolated from its stem wood in the early ‘70s, and recently characterized *in situ* and identified in bark extracts, and their antifungal and termiticidal activities have been described (Franca et al. 1972; Fu et al. 2018, 2019; Houël et al. 2017; Rodrigues et al. 2010, 2011). As part of the cited work was performed by member of our team, we were able, following the previously described protocols, to characterize the chemical composition of the larvicidal extract and confirm the presence of the two γ-lactones rubrenolide and rubrynolide. We also highlighted during this project the strong larvicidal activity of these two compounds against *Ae. aegypti*, with respective LC_{50} of 3.84 ± 0.02 and 0.60 ± 0.02 for rubrynolide and rubrenolide at 24 h, and 2.11 ± 0.04 and 0.30 ± 0.02 µg/mL at 48 h, alongside with a measured value of 3.15 ± 0.02 µg/mL for the crude wood extract at 24 h and 2.06 ± 0.02 µg/mL at 48 h (Falkowski et al. 2016). Following a patent deposit concerning the bioactivity of the wood extract and its constituents, a further evaluation of the larvicidal activity and its mechanisms will be performed, alongside with the characterization of its ecotoxicity (Falkowski et al. N° WO2016046489 A1). Cytotoxicity of *S. rubra* was not evaluated in this study on KB and MRC5 cells, however it was demonstrated before that the two major compounds of wood and bark extracts, rubrenolide and rubrynolide, displayed low cytotoxicities on NIH-3T3 mammalian fibroblasts cells with IC_{50} values > 100 µg/mL in each case (Rodrigues et al. 2010). Complementary results have also been published, which highlighted notable toxicity for rubrenolide against several human cancer cell lines (Tofoli et al. 2016). This point will thus be further evaluated in the context of an ongoing project which aims at deepening the above-described results regarding the crude extract and isolated compounds and progressing towards the development of a marketable product.

3.3. Multivariate analysis

A generalized linear model (GLM) regression identified that solvents, organs, family and location are significantly associated to larvicidal potential of the extracts, while light, resources and vegetation type don't (Table 4). A second model was run using only those first four factors and a Tukey HSD test was computed on this second model. The significantly different comparisons are listed in Table 5 and full data are available in Table S2.

Variable	Degree of freedom	Sum of square	Mean of square	F-value	P-value

Solvent	3	30.79	10.264	13.943	1.19e-08
Botanical family	35	46.97	1.342	1.823	0.00367
Location	8	62.24	7.781	10.569	1.88e-13
Light	2	1.32	0.658	0.894	0.40986
Ressource	2	0.26	0.129	0.175	0.83941
Vegetation type	3	3.48	1.162	1.578	0.19420
Plant organs	9	19.57	2.174	2.953	0.00209
Residuals	389	286.37	0.736		

Table 4 Anova analysis on quasi-Poisson generalized linear model (GLM) results

		CI 95%		
	Differences	Lower	Upper	P-value
Solvent [a]				
W / PE	-0.707	-1.046	-0.368	< 0.001
PE / M	0.584	0.283	0.885	< 0.001
W / EA	-0.479	-0.788	-0.171	< 0.001
M / EA	-0.356	-0.622	-0.091	0.003
Organs				
Inflorescence / Aerial parts	1.334	0.229	2.438	0.006
Stems / Inflorescence	-1.234	-2.301	-0.166	0.01
Leaves / Inflorescence	-1.201	-2.259	-0.142	0.013
Fruits / Aerial parts	1.171	0.067	2.276	0.028
Stems / Fruits	-1.072	-2.139	-0.004	0.048
Family				
Lauraceae / Annonaceae	1.704	0.222	3.187	0.006
Lauraceae / Bignoniaceae	1.82	0.021	3.62	0.043
Lauraceae / Costaceae	1.701	0.091	3.31	0.023
Lauraceae / Dilleniaceae	2.411	0.261	4.561	0.009
Lauraceae / Euphorbiaceae	1.8	0.35	3.25	0.001
Lauraceae / Fabaceae	1.697	0.301	3.093	0.002
Loranthaceae / Lauraceae	-1.949	-3.802	-0.096	0.025
Malpighiaceae / Lauraceae	-1.979	-3.513	-0.444	0.001
Malvaceae / Lauraceae	-2.05	-3.973	-0.126	0.02
Meliaceae / Lauraceae	-1.889	-3.645	-0.133	0.018
Sapindaceae / Lauraceae	-1.61	-3.118	-0.101	0.02
Sapotaceae / Lauraceae	-1.93	-3.729	-0.131	0.018

Siparunaceae / Lauraceae	-1.91	-3.709	-0.111	0.022
Solanaceae / Lauraceae	-1.543	-3.064	-0.023	0.041
Location [b]				
Si-Mo	-2.353	-3.328	-1.377	< 0.001
Rg-Mo	-2.454	-3.48	-1.428	< 0.001
Mo-Mc	2.414	1.415	3.413	< 0.001
Mo-Ma	2.391	1.389	3.393	< 0.001
Mo-Ko	2.383	1.393	3.373	< 0.001
Mt-Mo	-2.581	-3.924	-1.238	< 0.001
Rm-Mo	-3.126	-5.251	-1.002	< 0.001
Ro-Mo	-3.898	-6.748	-1.048	0.001

[a] W: water. PE: petroleum ether. M: methanol. EA: ethyl acetate

[b] Si: Sinnamary. Mo: Montsinéry-Tonnegrande. Rg: Régina. Mc: Macouria. Ma: Mana. Ko: Kourou. Mt: Matoury. Rm: Rémire-Montjoly. Ro: Roura

Table 5 Tukey HSD significant pairwise differences between variables

Analysis revealed that mortalities observed for methanol and water extracts were significantly lower than those obtained for petroleum ether and ethyl acetate extracts. Similar results had been previously reported in structure-activity studies (Carreno Otero et al., 2014; Santos et al. 2010). It can be assumed that more polar compounds are less prone to penetrate larvae cuticles, whereas lipophilic compounds have higher affinity for cell membranes and insect cuticles (Chen et al. 2014; Santos et al. 2010). In a study comparing the larvicidal, morphological and behavorial response of *Ae. aegypti* to various extracts of *Argemone mexicana* L. (Papaveraceae), apolar extracts were shown to be the most efficient, inducing modification of larvae cuticles (Warikoo and Kumar, 2013). Our dataset reinforces the interest of lipophilic extracts and compounds as larvicidal products.

Among plant organs (bark, wood, stem, leaves, roots, aerial parts, whole plant, inflorescence and fruits), mortalities induced by the inflorescence extracts were significantly higher than for aerial parts, stems and leaves. Fruits also induced higher mortality than aerial parts and stems. Inflorescences were only collected from *Costus* species (*C. erythrothyrsus*, *C. spiralis* var. *villosus*, *C*. cf. *spiralis*) and among the 7 tested extracts, 2 exhibited strong larvicidal potential (97-100% mortality) whereas the other 5 were inactive (0-2% mortality). Fruits were collected from 3 species (*Matayba arborescens* and *Cupania scrobitulata*, Sapindaceae, *Tetracera asperula*, Dilleniaceae) and alongside the leaves of *Maytenus* sp. (Celastraceae). Over 9 tested extracts 4 were moderately active (32 to 64% larval mortality) whereas the remaining 5 were inactive (0-1% mortality), including the 2 *Tetracera* extracts (Table S1 Supporting Information). As discussed above, particular cases (damaged *Costus* inflorescence) and chemotaxonomy (Celastraceae and Sapindaceae being well-known insecticidal plants) may explain part of these results. However, the fact that reproductive organs (fruits and inflorescences) exhibit significantly higher larvicidal effect than non-reproductive organs (aerial parts, stems and leaves) is a point of interest in the light of plant species defense. In their work, McCall and Fordyce could not conclude on a possible more intense defense allocation in flowers compared to leaves (McCall and Fordyce 2010). This result possibly originated either from the fact that flowers are not so more valuable than leaves, or simply from a lack of power of the analysis due to a reduced dataset. A recent work for its part demonstrated that wild tobacco flowers accumulate large amounts of defensive compounds, which expression is specifically regulated by jasmonate phytohormones signaling (Li et al. 2017). Moreover, reproductive tissues (including anthers, nectary, ovary, style and stigma) where shown to exhibit higher relative levels of defense-related compounds than vegetative tissues (leaf, root, stem and seed) in a metabolic specialization study of the *Nicotiana attenuata* Torr. ex S. Watson (Solanaceae) model species (Li et al. 2016). Also, the comparison of the natural variation in glucosinolate between vegetative and reproductive tissues in *Boechera stricta* (Graham) Al-Shehbaz (Brassicaceae) revealed much higher concentrations of these defense compounds in fruits compared to leaves (Keith and Mitchell-Olds, 2017). In our case, insecticide activity was detected in inflorescence and fruits extracts of *Costus* and *Cupania* species while leaves and stem extracts were all inactive. For *Maytenus* and *Matayba* extracts, the observation of the dataset does not lead to obvious conclusions concerning defense allocation. In our study, roots or barks were not highlighted as organ leading to higher proportion of larvicidal extracts. However, these tissues may be of interest in a wider dataset. For example, higher levels of glucosinolate were detected in roots than in shoots of several species, and a higher chemical diversity of both monoterpenes and sesquiterpenes were released by barks compared to leaves immediately after mechanical damage for 178 individual trees belonging to 55 angiosperm species in French Guiana (Courtois et al. 2012; Tsunoda et al. 2017). This later finding was attributed to a larger investment in chemical defenses in the bark. Overall, our data together with the above cited literature suggest that plant organs are differently protected against pests. More active insecticides are found in reproductive organs, and recent herbivory/damage can significantly increase the probability to obtain active extracts. The choice of lipophilic extraction solvent is also critical.

Results concerning families and location are difficult to interpret due to the small size of the dataset. Although expected according to other works, light, resource availability and vegetation type did not significantly affect insecticide potential (Endara and Coley, 2011; Fine et al. 2006, 2013; Smilanich et al. 2016). One reason may be that the objective of developing botanical insecticides prompted us to investigate specifically plant qualitative defense compounds (small weight highly active molecules). These do not represent the totality of plant defensive arsenal. Quantitative defense compounds, such as tannins, are not accessible by these techniques (De Almeida et al. 2005).

4. Conclusion

The above discussed examples distinctly point out the fact, highlighted by Isman and Grieneisen (2014), that collecting a single sample from a single specimen does not allow to conclude on the interest of a given species as a new source of insecticide, and that chemical characterization of the studied extracts can clearly add value to this type of study. Moreover, we also exemplified that plant defensive chemistry mechanisms are crucial while trying to discover insecticidal products, even if the search for toxic compounds only encompasses a small facet of this highly complex machinery. Multivariate analysis allowed us to identify lipophilic solvents as the most interesting to yield insecticide extracts, and highlighted the fact that extending screening to various plant tissues, in particular reproductive organs, could lead to new promising larvicidal compounds. Analyzing existing dataset and conducting screening studies inspired by the functional role of secondary metabolites in nature, in the light of the chemistry of defense and with the understanding of the mechanisms driving resource allocations as proposed by Berenbaum or Miresmailli and Isman, could therefore help renewing the old-fashioned field of insecticidal natural products (Berenbaum 1995; Miresmailli and Isman 2014).

Supporting information

Supporting information may be found in the online version of this article.

Conflict of interest

On behalf of all authors, the corresponding authors state that there is no conflict of interest.

Acknowledgment

This work is part of the INSECTICIDES project funded by Europe (European Regional Development Fund Operational Programme, PRESAGE N°31220), French Guiana Regional Council and the Air Liquide Foundation. This research was part of the Laboratory of Excellence “Centre de la Biodiversité Amazonienne” [Labex CEBA (CEBA, ref ANR-10-LABX-25-01)] and of the STRonGer consortium (Institut Pasteur de la Guyane). This work benefited from an “Investissement d’Avenir” grant managed by Agence Nationale de la Recherche (Infrastructure Nationale en Biologie Santé “ANAEE-France” ANR-11-INBS-0001) through the use of the U3E INRA1036 PEARL platform.

The authors thank Bruno Clair (CNRS/UMR EcoFoG) and collaborators for providing *Bagassa guianensis* Aubl. (Moraceae) bark andexpress their gratitude to Bruno Hérault (CIRAD/UMR EcoFoG) for helping in statistical analysis. The authors also thank Vincent Jacquet for illustrating this article through the design of the graphical abstract.

References

Abílio AP, Abudasse G, Kampango A, Candrinho B, Sitoi S, Luciano J, Tembisse D, Sibindy S, de Almeida APG, Garcia GA, David MR, Maciel-de-Freitas R, Gudo ES (2018) Distribution and breeding sites of Aedes aegypti and Aedes albopictus in 32 urban/peri-urban districts of Mozambique: implication for assessing the risk of arbovirus outbreaks. PLoS Negl Trop Dis. 12:e0006692, https://doi.org/10.1371/journal.pntd.0006692.

Abbott W (1925) A method of computing the effectiveness of an insecticide. J Econ Entomol 18:265–267, https://doi.org/10.1093/jee/18.2.265a

Agrawal AA, Weber MG (2015) On the study of plant defence and herbivory using comparative approaches: how important are secondary plant compounds. Ecol Lett 18:985-991, https://doi.org/10.1111/ele.12482

Alvarenga N, Ferro EA (2005) Bioactive triterpenes and related compounds from Celastraceae. In: Atta-ur-Rahman (ed) Studies in natural products chemistry vol. 30 - Bioactive natural products (Part K), Elsevier, pp.635-702

Becerra JX (2007) The impact of herbivore-plant coevolution on plant community structure. Proc Natl Acad Sci USA 104:7483-7488, https://doi.org/10.1073_pnas.0608253104

Benelli G (2015) Research in mosquito control: current challenges for a brighter future. Parasitol Res 114:2801-2805, https://doi.org/10.1007/s00436-015-4586-9

Benelli G, Mehlhorn H (2016) Declining malaria, rising of dengue and Zika virus: insights for mosquito vector control. Parasitol Res 115:1747-1754, https://doi.org/10.1007/s00436-016-4971-z

Berenbaum MR (1995) The chemistry of defense: theory and practice. Proc Natl Acad Sci USA 92:2-8, https://doi.org/10.1073/pnas.92.1.2

Borges JCM, Haddi K, Oliveira EE, Andrade BS, Nascimento VL, Melo TS, Didonet J, Carvalho JCT, Cangussu AS, Soares IM, Ascencio SD, Raposo NRB, Aguiar RWS (2019) Mosquiticidal and repellent potential of formulations containing wood residue extracts of a Neotropical plant, Tabebuia heptaphylla. Ind Crops Prod 129:424-433, https://doi.org/10.1016/j.indcrop.2018.12.022

Boulogne I, Petit P, Ozier-Lafontaine H, Desfontaines L, Loranger-Merciris G (2012) Insecticidal and antifungal chemicals produced by plants: a review. Environ Chem Lett 10:325-347, https://doi.org/10.1007/s10311-012-0359-1

Carreño Otero AL, Vargas Méndez LY, Duque LJE, Kouznetsov VV (2014) Design, synthesis, acetylcholinesterase inhibition and larvicidal activity of girgensohnine analogs on *Aedes aegypti*, vector of dengue fever. Eur J Med Chem 78:392-400, https://doi.org/10.1016/j.ejmech.2014.03.067

Carvalho FD, Moreira LA (2017) Why is *Aedes aegypti* Linnaeus so successful as a species? Neotrop Entomol 46:243-255, https://doi.org/10.1007/s13744-017-0520-4

Chen X, Mukwaya E, Wong M-S and Zhang Y (2014) A systematic review on biological activities of prenylated flavonoids. Pharm Biol 52:655-660, https://doi.org/10.3109/13880209.2013.853809

Coley PD, Bryant JP, Chapin FS (1985) Resource availability and plant antiherbivore defense. *Science* 230:895–899, https://doi.org/10.1126/science.230.4728.895

Cos P, Vlietlinck AJ, Vanden Berghe D, Maes L (2006) Anti-infective potential of natural products: How to develop a stronger in vitro 'proof-of-concept'. J Ethnopharmacol 106:290-302, https://doi.org/10.1016/j.jep.2006.04.003

Courtois EA, Baraloto C, Paine CET, Petronelli P, Blandinieres P-A, Stien D, Houël E, Bessiere J-M, Chave J (2012) Differences in volatile terpene composition between the bark and leaves of tropical tree species. Phytochemistry 82:81-88, https://doi.org/10.1016/j.phytochem.2012.07.003

Cuca-Suárez LEC, Mendoza-Meza DL, Álvarez-Caballero J, Macías-Villamizar V, Coy-Barrera ED (2012) Acaricide activity of Lauraceae extracts against domiciliary mites *Dermatophagoides farinae* and *Blomia tropicalis*. Rev Cubana Plant Med 17:308-319, https://doi.org/

Da Silva TBC, Alves VL, Mendonça LVH, Conserva LM, da Rocha EMM, Andrade EHA, Lemos RPL (2004) Chemical constituents and preliminary antimalarial activity of *Humiria balsamifera*. Pharm Biol 42:94-97, https://doi.org/10.1 OX011 38802004905 10702

De Almeida CFCBR, De Lima E Silva TC, De Amorim ELC, Maia MBDS, De Albuquerque UP (2005) Life strategy and chemical composition as predictors of the selection of medicinal plants from the caatinga (Northeast Brazil). J Arid Environ 62:127-142, https://doi.org/10.1016/j.jaridenv.2004.09.020

Deepa MA, Narmatha Bai V (2010) Bioinsecticidal compounds of Celastraceae – the Spindle Tree family. Int J Bot 6:220-227, https://doi.org/10.3923/ijb.2010.220.227

Dias CN, Moraes DFC (2014) Essential oils and their compounds as *Aedes aegypti* L. (Diptera: Culicidae) larvicides: review. Parasitol Res 113:565-592, https://doi.org/10.1007/s00436-013-3687-6

Diaz M and Rossini C (2012) Bioactive natural products from Sapindaceae deterrent and toxic metabolites against insects. In: Perveen F (ed) Insecticides - Pest Engineering, InTech, pp. 287-308

Domingues SJS, de Souza TF, Soares AMS, Jacinto T, Machado OLT (2007) Activation of phospholipase PLA2 actvity in *Ricinus communis* leaves in response to mechanical wounding. Braz J Plant Physiol 19:35-42, https://doi.org/10.1590/S1677-04202007000100004

Dorla E, Gauvin-Bialecki A, Deuscher Z, Allibert A, Grondin I, Deguine J-P, Laurent P (2017) Insecticidal activity of the leaf essential oil of *Peperomia borbonensis* Miq. (Piperaceae) and its major components against the Melon Fly *Bactrocera cucurbitae* (Diptera: Tephritidae). Chem Biodiv 14:e1600493, https://doi.org/10.1002/cbdv.201600493

Dusfour I, Thalmensy V, Gaborit P, Issaky J, Carinci R, Girod R (2011) Multiple insecticide resistance in *Aedes aegypti* (Diptera: Culicidae) populations compromises the effectiveness of dengue vector control in French Guiana. Mem Inst Oswaldo Cruz 106: 346-352

Ehrlich PR, Raven PH (1964) Butterflies and plants: a study in coevolution. Evolution 18:586–608, https://doi.org/10.1590/s0074-02762011000300015

Endara MJ,Coley PD (2011) The resource availability hypothesis revisited: a meta-analysis. Funct Ecol 25:389-398, doi : 10.1111/j.1365-2435.2010.01803.x

Falkowski M, Rodrigues A, Eparvier V, Dusfour I, Houël E, Stien D (2014) Propriétés insecticides d'un extrait de *Sextonia rubra*, et de ses constituants, Patent N°WO2016046489 A1

Falkowski M, Jahn-Oyac O, Ferrero E, Issaly J, Eparvier V, Rodrigues AMS, Stien D, Houël E and Dusfour I (2016) Assessment of a simple compound-saving method to study insecticidal activity of natural extracts and pure compounds against mosquito larvae. J Am Mosq Control Assoc, 32:337-340, https://doi.org/10.2987/16-6613.1

Fauci AS, Morens DM (2016) Zika Virus in the Americas - Yet Another Arbovirus Threat. N Engl J Med 374:601-604, https://doi.org/10.1056/NEJMp1600297

Faucon F, Dusfour I, Gaude T, Navratil V, Boyer F, Chandre F, Sirisopa P, Thanispong K, Juntarajumnong W, Poupardin R, Chareonviriyaphap T, Girod R, Corbel V, Reynaud S, David JP (2015) Identifying genomic changes associated with insecticide resistance in the dengue mosquito *Aedes aegypti* by deep targeted sequencing. Genome Res 25:1347-1359, https://doi.org/10.1101/gr.189225.115

Feeny PP (1976) Plant apparency and chemical defence. In: Wallace J, Mansell R (ed) Biochemical interactions between plants and insects. Recent advances in phytochemistry. Academic Press, New York, NY, USA, pp. 1-40

Fine PA, Metz MR, Lokvam J, Mesones I, Zuniga JMA, Lamarre GPA, Pilco MV, Baraloto C (2013) Insect herbivores, chemical innovation, and the evolution of habitat specialization in Amazonian trees. Ecology 94:1764-1775, https://doi.org/10.1890/12-1920.1

Fine PV, Miller ZJ, Mesones I, Irazuzta S, Appel HM, Stevens MH, Sääksjärvi I, Schultz JC, Coley PD (2006) The growth-defense trade-off and habitat specialization by plants in Amazonian forests. Ecology 87:S150-62

Fraenkel G (1959) The raison d'être of secondary plant substances. Science 129:1466–1470, https://doi.org/10.1126/science.129.3361.1466

Franca NC, Gottlieb OR, Coxon DT, Ollis WD (1972) Constitutions of rubrenolide and rubrynolide: an alkene-alkyne pair from *Nectandra rubra*. J Chem Soc, Chem Comm 514-515, https://doi.org/10.1039/C39720000514

Fu T, Touboul D, Della-Negra S, Houël E, Amusant N, Duplais C, Fisher GL, Brunelle A (2018) Tandem MS imaging and in situ identification of bioactive wood metabolites in Amazonian tree species *Sextonia rubra*. Anal Chem 90:7535-7543, https://doi.org/10.1021/acs.analchem.8b01157

Fu T, Houël E, Amusant N, Touboul D, Genta-Jouve G, Della-Negra S, Fisher GL, Brunelle A, Duplais C (2019) Biosynthetic investigation of γ-lactones in *Sextonia rubra* wood using in situ TOF-SIMS MS/MS imaging to localize and characterize biosynthetic intermediates. Sci Rep 9:1928, https://doi.org/10.1038/s41598-018-37577-5

George DR, Finn RD, Graham KM, Sparagano OAE (2014) Present and future potential of plant-derived products to control arthropods of veterinary and medical significance. Parasit *Vectors* 7:28-39, https://doi.org/10.1186/1756-3305-7-28

Gerwick BC, Sparks TC (2014) Natural products for pest control: an analysis of their role, value and future. Pest Manag Sci 70:1169-1185, https://doi.org/10.1002/ps.3744

Harada K, Suomalainen M, Uchida H, Masui H, Ohmura K, Kiviranta J, Niku-Paavola ML, Ikemoto T (2000) Insecticidal compounds against mosquito larvae from *Oscillatoria agardhii* strain 27. Environ Toxicol 15:114-119, https://doi.org/10.1002/(SICI)1522-7278(2000)15:2<114::AID-TOX7>3.0

Higgs S, Vanlandingham D (2015) Chikungunya virus and its mosquito vectors. Vector Borne Zoonotic Dis 15:231-240, https://doi.org/10.1089/vbz.2014.1745

Houël E, Rodrigues AMS, Nicolini E, Ngwete O, Duplais C, Stien D, Amusant N (2017) Natural durability of *Sextonia rubra*, an Amazonian tree species: description and origin. IRG/WP 17-10887, Proceedings IRG Annual Meeting; ISSN 2000-8953

Isman MB (2006) Botanical insecticides, deterrents and repellents in modern agriculture and an increasingly regulated world. Annu Rev Entomol 51:45-66, https://doi.org/10.1146/annurev.ento.51.110104.151146

Isman MB (2015) A renaissance for botanical insecticides? Pest Manag Sci 71:1587-1590

Isman MB, Grieneisen ML (2014) Botanical insecticide research: many publications, limited useful data. Trends Plant Sci 19:140-145, https://doi.org/10.1002/ps.4088

Jeevani Osadee Wijekoon MM, Karimand AA, Bhat R (2011) Evaluation of nutritional quality of torch ginger (*Etlingera elatior* Jack.) inflorescence. Int Food Res J 18:1415–1420

Jullian V, Bonduelle C, Valentin A, Acebey L, Duigou A-G, Prévost M-F, Sauvain M (2005) New clerodane diterpenoids from *Laetia procera* (Poepp.) Eichler (Flacourtiaceae), with antiplasmodial and antileishmanial activities. Bioorg Med Chem Lett 15:5065–5070, https://doi.org/10.1016/j.bmcl.2005.07.090

Keith RA, Mitchell-Odds T (2017) Testing the optimal defense hypothesis in nature: variation for glucosinolate profiles within plants. PloS One 12:e0180971, https://doi.org/10.5061/dryad.b2t42.

Lamarre GPA, Baraloto C, Fortunel C, Davila N, Mesones I, Rios JG, Rios M, Valderrama E, Pilco MV, Fine PVA (2012) Herbivory, growth rates, and habitat specialization in tropical tree lineages : implications for Amazonian beta-diversity. Ecology 93:5195-5210, https://doi.org/10.1890/11-0397.1

L'Azou M, Taurel A-F, Flamand C, Quénel P (2014) Recent epidemiological trends of dengue in the French territories of the Americas (2000–2012): a systematic literature review. PLoS Negl Trop Diseases 8:e3235, https://doi.org/10.1371/journal.pntd.0003235

Li D, Heiling S, Baldwin IT, Gaquerel E (2016) Illuminating a plant's tissue-specific metabolic diversity using computational metabolomics and information theory. Proc Natl Acad Sci USA E7610–E7618, https://doi.org/10.1073/pnas.1610218113

Li R, Wang M, Schuman MC, Weinhold A, Schäfer M, Jimenez-Aleman GH, Barthel A, Baldwin IT (2017) Flower-specific jasmonate signaling regulates constitutive floral defense in wild tobacco. Proc Natl Acad Sci USA E7205-E7214, https://doi.org/10.1073/pnas.1703463114

Lija-Escaline J, Senthil-Nathan S, Thanigaivel A, Pradeepa V, Vasantha-Srinivasan P, Ponsankar A, Edwin ES, Selin-Rani S, Abdel-Megeed A (2015) Physiological and biochemical effects of botanical extract from *Piper nigrum* Linn (Piperaceae) against the dengue vector. Parasitol Res 114:4239-4249, https://doi.org/10.1007/s00436-015-4662-1

Lima E, Paiva M, Araújo A, Da Silva E, Da Silva U, Oliveira L, Santana A, Barbosa C, Neto C, Goulart M, Wilding C, Ayres C and Santos M (2011) Insecticide resistance in *Aedes aegypti* populations from Ceará, Brazil. Parasite Vector 4:5, https://doi.org/10.1186/1756-3305-4-5

Macêdo ME, Consoli RAGB, Grandi TSM, dos Anjos AMG, de Oliveira AB, Mendes NM, Queiroz RO, Zani CL (1997) Screening of Asteraceae (Compositae) plant extracts for larvicidal activity against *Aedes fluviatilis* (Diptera : Culicidaea). Mem Inst Oswaldo Cruz 92:565-570, https://doi.org/10.1590/s0074-02761997000400024

Marques AM, Kaplan MAC (2015) Active metabolites of the genus *Piper* against *Aedes aegypti*: natural alternative sources for dengue vector control. Univ Sci 20:61-82, https://doi.org/10.11144/Javeriana.SC20-1.amgp

McCall AC, Fordyce JA (2010) Can optimal defence theory be used to predict the distribution of plant chemical defences? J Ecol 98:985-992, https://doi.org/10.1111/j.1365-2745.2010.01693.x

McKey D (1974) Adaptive patterns in alkaloid physiology. Am Nat 108:305-320.

Miresmailli S, Isman MB (2015) Botanical insecticides inspired by plant–herbivore chemical interactions. Trends Plant Sci 19:29-35, https://doi.org/10.1086/282909

Moyes CL, Vontas J, Martins AJ, Ng LC, Koou SY, Dusfour I, Raghavendra K, Pinto J, Corbel V, David J-P, Weetman D (2017) Contemporary status of insecticide resistance in the major *Aedes* vectors of arboviruses infecting humans. PLoS Negl Trop Dis 11:e0005625, doi : 10.1371/journal.pntd.0005625

Nirma C, Rodrigues AMS, Basset C, Chevolot L, Girod R, Moretti C, Stien D, Dusfour I, Eparvier V (2012) Larvicidal activity of isoflavonoids from *Muellera frutescens* extracts against *Aedes aegypti*. Nat Prod Comm 7:1-4, https://doi.org/10.1177/1934578X1200701016

Oliveira PV, Ferreira JC, Moura FS, Lima GS, de Oliveira FM, Oliveira PES, Conserva LM, Giulietti AM, Lemos RPL (2010) Larvicidal activity of 94 extracts from ten plant species of northeastern of Brazil against *Aedes aegypti* L. (Diptera: Culicidae). Parasitol Res 107:403-407, https://doi.org/10.1007/s00436-010-1880-4

Pavela R (2015) Essential oils for the development of eco-friendly mosquito larvicides: a review. Ind Crops Prod 76:174–187, http://dx.doi.org/10.1016/j.indcrop.2015.06.050

Pavela R, Maggi F, Iannarelli R, Benelli G (2019) Plant extracts for developing mosquito larvicides: From laboratory to the field, with insights on the modes of acton. Acta Trop 193: 236-271, https://doi.org/10.1016/j.actatropica.2019.01.019

Pipithsangchan S, Morallo-Rejesus B (2005) Insecticidal activity of diosgenin isolated from three species of grape ginger (*Costus* spp.) on the diamondback moth, *Plutella xylostella* (L.). Philipp Agric Sci 88:317-327

Rahuman AA, Venkatesan P, Gopalakrishnan G (2008) Mosquito larvicidal activity of oleic and linoleic acids isolated from *Citrullus colocynthis* (Linn.) Schrad. Parasitol Res 103:1383-1390, https://doi.org/10.1007/s00436-008-1146-6

Ramsewak RS, Nair MG, Murugesan S, Mattson WJ, Zasada J (2001) Insecticidal fatty acids and triglycerides from *Dirca palustris*. J Agric Food Chem 49:5852-5856, https://doi.org/10.1021/jf010806y

Rhoades D, Cates RG (1976) Toward a general theory of plant antiherbivore chemistry. In: Wallace J, Mansell R (ed) Biochemical interactions between plants and insects. Recent advances in phytochemistry. Academic Press, New York, NY, USA, pp. 155-204

Richards LA, Dyer LA, Forister ML, Smilanich AM, Dodson CD, Leonard MD, Jeffrey CS (2015). Phytochemical diversity drives plant-insect community diversity. Proc Natl Acad Sci USA 112:10973-10978, https://doi.org/10.1073/pnas.1504977112

Rodrigues AMS, Theodoro PNET, Eparvier V, Basset C, Silva MRR, Beauchêne J, Espindola LS, Stien D (2010) Search for antifungal compounds from the wood of durable tropical trees. J Nat Prod 73:1706-1707, https://doi.org/10.1021/np1001412

Rodrigues AMS, Amusant N, Beauchêne J, Eparvier V, Leménager N, Baudassé C, Espíndola LS, Stien D (2011) The termiticidal activity of *Sextonia rubra* (Mez) van der Werff (Lauraceae) extract and its active constituent rubrynolide. Pest Manag Sci 67:1420-1423, https://doi.org/10.1002/ps.2167

Rojas CM, Senthil-Kumar M, Tzin V, Mysore KS (2014) Regulation of primary plant metabolism during plant-pathogen interactions and its contribution to plant defense. Front Plant Sci 5:17, https://doi.org/10.3389/fpls.2014.00017

Ryu SB, Lee HY, Doelling JH, Palta JP (2005) Characterization of a cDNA encoding *Arabidopsis* secretory phospholipase A2-α, an enzyme that generates bioactive lysophospholipids and free fatty acids. Biochim Biophys Acta BBA -Mol Cell Biol Lipids 1736:144-151, https://doi.org/10.1016/j.bbalip.2005.08.005

Sacchi R, Addeo F, Paolillo L (1997) ^{1}H and ^{13}C NMR of virgin olive oil. An overview. Magn Reson Chem 35:S133-S145, https://doi.org/10.1002/(SICI)1097-458X(199712)35:13<S133::AID-OMR213>3.0.CO;2-K

Santos SRL, Silva VB, Melo MA, Barbosa JFF, Santos RLC, De Sousa DP, Cavalcanti SCH (2010) Toxic effects on and structure-toxicity relationships of phenylpropanoids, terpenes, and related compounds in *Aedes aegypti* larvae. Vector Borne Zoonotic Dis 10:1049-1054, https://doi.org/10.1089/vbz.2009.0158

Santos GGA, Santos BA, Nascimento HEM and Tabarelli M (2012) Contrasting demographic structure of short- and long-lived pioneer tree species on Amazonian forest edges. Biotropica 44:771-778, https://doi.org/10.1111/j.1744-7429.2012.00882.x

Santos LMM, Nascimento JS, Santos MAG, Marriel NB, Bezerra-Silva PC, Rocha SKL, Silva AG, Correia MTS, Paiva PMG, Martins GF, Navarro DMAF, Silva MV, Napoleão TH (2017) Fatty acid-rich volatile oil from *Syagrus coronata* seeds has larvicidal and oviposition-deterrent activities against *Aedes aegypti.* Physiol Mol Plant Pathol 100:35-40, https://doi.org/10.1016/j.pmpp.2017.05.008

Simmons CP, Farrar JJ, Chau NVV, Wills B (2012) Dengue. N Engl J Med 366:1423-1432, https://doi.org/ 10.1056/NEJMra1110265

Smilanich AM, Fincher RM, Dyer LA (2016) Does plan apparency matter? Thirty years of data provide limited support but reveal clear patterns of the effects of plant chemistry on herbivores. New Phytologist 210:1044-1057, https://doi.org/10.1111/nph.13875

Specht CD, Stevenson DW (2006) A new phylogeny-based generic classification of Costaceae (Zingiberales). Taxon 55:153-163, https://doi.org/10.1600/036364415X686404

Surendra Kumar M, Aswathy TN, Suhail CN, Astalakshmi N, Babu G (2014) Studies on *Costus speciosus* Koen alcoholic extract for larvicidal activity. Int J Pharmacogn Phytochem Res 5:328-329

Tsunoda T, Krosse S, Van Dam NM (2017) Root and shoot glucosinolate allocation patterns follow optimal defence allocation theory. J Ecol 105:1256-1266, https://doi.org/10.1111/1365-2745.12793

Tempête C, Werner G, Favre F, Roja A, Langlois N (1995) *In vitro* cytostatic activity of 9-demethoxyporothramycin B. Eur J Med Chem 30:647-650, https://doi.org/10.1016/0223-5234(96)88281-X

Tófoli D, Martins LAV, Matos MFC, Garcez WS, Garcez FG (2016) Antiproliferative butyrolactones from *Mezilaurus crassiramea.* Planta Med Lett 3:e14-e16, https://doi.org/10.1055/s-0035-1568355

Touré S, Nirma C, Falkowski M, Dusfour I, Boulogne I, Jahn-Oyac A, Coke M, Azam D, Girod R, Moriou C, Odonne G, Stien D, Houël E, Eparvier V (2017) *Aedes aegypti* larvicidal sesquiterpene alkaloids from *Maytenus oblongata*. J Nat Prod 80:384-390, https://doi.org/10.1021/acs.jnatprod.6b00850

Wang C, Lü L, Zhang A, Liu C (2013) Repellency of selected chemicals against the bed bug (Hemiptera: Cimicidae). J Econ Entomol 106:2522-2529, https://doi.org/10.1603/EC13155

Warikoo R, Kumar S (2013) Impact of *Argemone mexicana* extracts on the cidal, morphological, and behavioral response of dengue vector, *Aedes aegypti* L. (Diptera: Culicidae). Parasitol Res 112:3477-3484, https://doi.org/10.1007/s00436-013-3528-7

World Health Organization (2005) Guidelines for Laboratory and Field Testing of Mosquito Larvicides. http://apps.who.int/iris/bitstream/10665/69101/1/WHO_CDS_WHOPES_GCDPP_2005.13.pdf

Zhang A, Klun JA, Wang S, Carroll JF, Debboun M (2009) Isolongifolenone: a novel sesquiterpene repellent of ticks and mosquitoes. J Med Entomol 46:100-106, https://doi.org/10.1603/033.046.0113

Supporting information

Towards the optimization of botanical insecticides research: a case study on *Aedes aegypti* larvicidal botanical extracts in French Guiana

Michaël Falkowski[1], Arnaud Jahn-Oyac[1], Guillaume Odonne[2], Claudiane Flora[1], Yannick Estevez[1], Seindé Touré[1,3], Isabelle Boulogne[1,4,5], Jean-Charles Robinson[6], Didier Béreau[6], Philippe Petit[4], Didier Azam[7], Maïra Coke[7], Jean Issaly[8], Pascal Gaborit[8], Didier Stien[9], Véronique Eparvier[3], Isabelle Dusfour[8,10*], Emeline Houël[1,*]

[1] CNRS, UMR EcoFoG, AgroParisTech, Cirad, INRA, Université des Antilles, Université de Guyane, 97300 Cayenne, France.

[2] Laboratoire Ecologie, Evolution, Interactions des Systèmes Amazoniens (LEEISA), CNRS, Université de Guyane, IFREMER, 97300 Cayenne, France.

[3] CNRS, Institut de Chimie des Substances Naturelles, UPR2301, Université Paris Saclay, 91198 Gif-sur-Yvette, France.

[4] Université des Antilles, Campus de Fouillole, 97157 Pointe-à-Pitre Cedex, Guadeloupe, France.

[5] UPRES-EA 4358 GlycoMev, Université de Rouen Normandie, 76821 Mont saint Aignan, France.

[6] Université de Guyane, Laboratoire COVAPAM, UMR QualiSud, Campus universitaire de Troubiran, BP 792, 97337 Cayenne cedex, France.

[7] Unité Expérimentale d'Ecologie et d'Ecotoxicologie Aquatique, INRA-U3E, 35042 Rennes, France.

[8] Institut Pasteur de la Guyane, Vectopôle Amazonien Emile Abonnenc, Unité Contrôle et Adaptation des vecteurs, 23 avenue Pasteur, BP6010, 97306 Cayenne cedex, France.

[9] Sorbonne Université, CNRS, Laboratoire de Biodiversité et Biotechnologie Microbienne, LBBM, Observatoire Océanologique, 66650 Banyuls-sur-mer, France.

[10] INRS-Institut Armand Frappier, Groupe recherche en écologie microbienne, 531 boulevard des prairies, H7V 1B7, Laval, QC, Canada,

* Correspondence to: Emeline Houël, CNRS, UMR EcoFoG, AgroParisTech, Cirad, INRA, Université des Antilles, Université de Guyane, 97300 Cayenne, France ; Tel.: +594 594 29 31 34 e-mail address: emeline.houel@ecofog.gf and Isabelle Dusfour, INRS-Institut Armand Frappier, Groupe recherche en écologie microbienne, 531 boulevard des prairies, H7V 1B7, Laval, QC, Canada, isabelle.dusfour@pasteur.fr

Fig. S1 ^1H NMR (400 MHz, $CDCl^3$) spectrum of the larvicidal fraction obtained from *Costus erythrothyrsus* (Costaceae) ethyl acetate extract inflorescence.

Table S1 Full dataset of the extracts tested against larvae of the susceptible laboratory strain Paea: botanical identification, extraction solvent, absolute mortality (number of dead larvae), geographical origin and environment and vegetation characterization

Table S2 Full dataset of Tukey HSD pairwise differences between variables

Fig. S1 ^{1}H NMR (400 MHz, $CDCl_3$) spectrum of the larvicidal fraction obtained from *Costus erythrothyrsus* (Costaceae) ethyl acetate extract inflorescence.

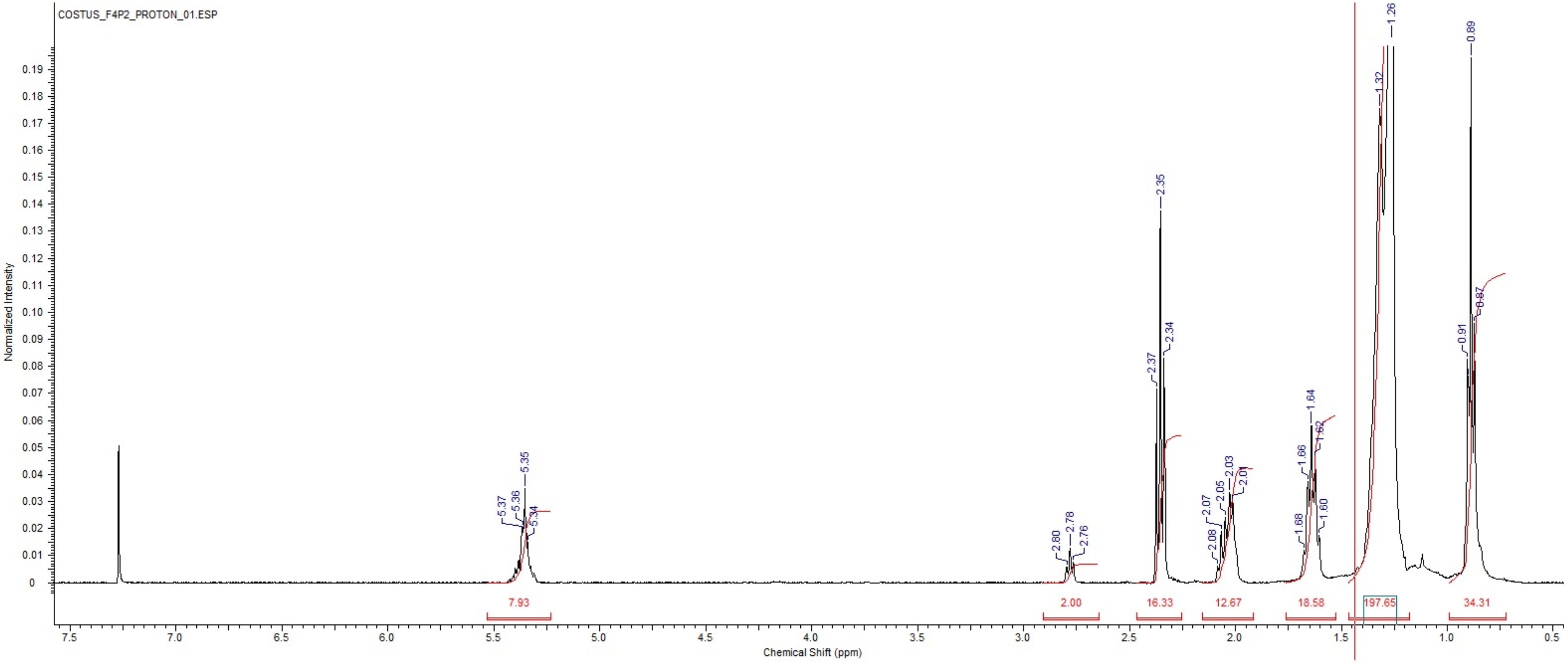


Table S1 Full dataset of the extracts tested against larvae of the susceptible laboratory strain Paea: botanical identification, extraction solvent, absolute mortality (number of dead larvae), geographical origin and environment and vegetation characterization

Voucher nb. [a]	Botanical family	Genus	Species	Plant organ [b]	Solvent [c]	Mortality	SD[d]	Localization [e]	Light (0= few / 2 = strong)	Resource (0= poor / 2 =rich)	Vegetation [f]
GO721	Annonaceae	*Anaxagorea*	*dolichocarpa*	L	EA	1	1	Ko	2	2	2
GO721	Annonaceae	*Anaxagorea*	*dolichocarpa*	L	M	1	1	Ko	2	2	2
GO721	Annonaceae	*Anaxagorea*	*dolichocarpa*	L	PE	3	2	Ko	2	2	2
GO721	Annonaceae	*Anaxagorea*	*dolichocarpa*	L	W	0	0	Ko	2	2	2
GO721	Annonaceae	*Anaxagorea*	*dolichocarpa*	St	EA	3	2	Ko	2	2	2
GO721	Annonaceae	*Anaxagorea*	*dolichocarpa*	St	M	0	0	Ko	2	2	2
GO721	Annonaceae	*Anaxagorea*	*dolichocarpa*	St	PE	5	1	Ko	2	2	2
GO721	Annonaceae	*Anaxagorea*	*dolichocarpa*	St	W	0	0	Ko	2	2	2
GO718	Annonaceae	*Guatteria*	*ouregou*	L	EA	0	0	Ko	2	2	3
GO718	Annonaceae	*Guatteria*	*ouregou*	L	M	0	0	Ko	2	2	3
GO718	Annonaceae	*Guatteria*	*ouregou*	L	PE	4	2	Ko	2	2	3
GO718	Annonaceae	*Guatteria*	*ouregou*	L	W	1	1	Ko	2	2	3
GO718	Annonaceae	*Guatteria*	*ouregou*	St	EA	1	1	Ko	2	2	3
GO718	Annonaceae	*Guatteria*	*ouregou*	St	M	2	1	Ko	2	2	3
GO718	Annonaceae	*Guatteria*	*ouregou*	St	PE	14	3	Ko	2	2	3
GO718	Annonaceae	*Guatteria*	*ouregou*	St	W	0	0	Ko	2	2	3
GO788	Annonaceae	*Xylopia*	*cayennensis*	L	EA	4	2	Ma	2	1	3
GO788	Annonaceae	*Xylopia*	*cayennensis*	L	M	0	0	Ma	2	1	3
GO788	Annonaceae	*Xylopia*	*cayennensis*	B	EA	1	1	Ma	2	1	3
GO788	Annonaceae	*Xylopia*	*cayennensis*	B	M	1	1	Ma	2	1	3
GO774	Annonaceae	*Xylopia*	*frutescens* var. *ferruginea*	L	EA	8	2	Ma	2	0	3
GO774	Annonaceae	*Xylopia*	*frutescens* var. *ferruginea*	L	M	1	1	Ma	2	0	3
GO774	Annonaceae	*Xylopia*	*frutescens* var. *ferruginea*	L	PE	54	7	Ma	2	0	3

GO774	Annonaceae	*Xylopia*	*frutescens* var. *ferruginea*	L	W	0	0	Ma	2	0	3
GO774	Annonaceae	*Xylopia*	*frutescens* var. *ferruginea*	B	EA	4	2	Ma	2	0	3
GO774	Annonaceae	*Xylopia*	*frutescens* var. *ferruginea*	B	M	1	1	Ma	2	0	3
GO774	Annonaceae	*Xylopia*	*frutescens* var. *ferruginea*	B	PE	23	5	Ma	2	0	3
GO774	Annonaceae	*Xylopia*	*frutescens* var. *ferruginea*	B	W	0	0	Ma	2	0	3
GO774	Annonaceae	*Xylopia*	*frutescens* var. *ferruginea*	St	EA	1	1	Ma	2	0	3
GO774	Annonaceae	*Xylopia*	*frutescens* var. *ferruginea*	St	M	0	0	Ma	2	0	3
GO774	Annonaceae	*Xylopia*	*frutescens* var. *ferruginea*	St	PE	38	8	Ma	2	0	3
GO774	Annonaceae	*Xylopia*	*frutescens* var. *ferruginea*	St	W	0	0	Ma	2	0	3
GO724	Apocynaceae	*Tabernaemontana*	*siphilitica*	AP	EA	0	0	Ko	2	2	1
GO724	Apocynaceae	*Tabernaemontana*	*siphilitica*	AP	M	1	1	Ko	2	2	1
GO724	Apocynaceae	*Tabernaemontana*	*siphilitica*	AP	PE	10	3	Ko	2	2	1
GO724	Apocynaceae	*Tabernaemontana*	*siphilitica*	AP	W	0	0	Ko	2	2	1
GO749	Apocynaceae	*Lacmellea*	*aculeata*	L	EA	15	3	Si	1	2	2
GO749	Apocynaceae	*Lacmellea*	*aculeata*	L	M	0	0	Si	1	2	2
GO749	Apocynaceae	*Lacmellea*	*aculeata*	L	PE	31	3	Si	1	2	2
GO749	Apocynaceae	*Lacmellea*	*aculeata*	L	W	0	0	Si	1	2	2
GO749	Apocynaceae	*Lacmellea*	*aculeata*	St	EA	0	0	Si	1	2	2
GO749	Apocynaceae	*Lacmellea*	*aculeata*	St	M	0	0	Si	1	2	2
GO749	Apocynaceae	*Lacmellea*	*aculeata*	St	PE	0	0	Si	1	2	2
GO749	Apocynaceae	*Lacmellea*	*aculeata*	St	W	1	1	Si	1	2	2
GO760	Asteraceae	*Bidens*	*cynapiifolia*	WP	EA	97	1	Mc	2	0	0
GO760	Asteraceae	*Bidens*	*cynapiifolia*	WP	M	2	1	Mc	2	0	0
GO760	Asteraceae	*Bidens*	*cynapiifolia*	WP	PE	1	1	Mc	2	0	0
GO795	Bignoniaceae	*Handroanthus*	*capitatus*	L	EA	4	2	Rg	2	0	2
GO795	Bignoniaceae	*Handroanthus*	*capitatus*	L	M	0	0	Rg	2	0	2
GO795	Bignoniaceae	*Handroanthus*	*capitatus*	St	EA	1	1	Rg	2	0	2
GO795	Bignoniaceae	*Handroanthus*	*capitatus*	St	M	1	1	Rg	2	0	2
GO727	Bignoniaceae	*Adenocalymma*	*moringifolium*	AP	EA	0	0	Ko	0	2	2
GO727	Bignoniaceae	*Adenocalymma*	*moringifolium*	AP	M	1	1	Ko	0	2	2

GO727	Bignoniaceae	*Adenocalymma*	*moringifolium*	AP	PE	3	2	Ko	0	2	2
GO727	Bignoniaceae	*Adenocalymma*	*moringifolium*	AP	W	0	0	Ko	0	2	2
GO789	Boraginaceae	*Varronia*	*schomburgkii*	AP	EA	21	3	Ma	1	2	2
GO789	Boraginaceae	*Varronia*	*schomburgkii*	AP	M	1	1	Ma	1	2	2
GO726	Celastraceae	*Maytenus*	*oblongata*	L	EA	0	0	Ko	2	2	2
GO726	Celastraceae	*Maytenus*	*oblongata*	L	M	1	1	Ko	2	2	2
GO726	Celastraceae	*Maytenus*	*oblongata*	L	PE	0	0	Ko	2	2	2
GO726	Celastraceae	*Maytenus*	*oblongata*	L	W	0	0	Ko	2	2	2
GO726	Celastraceae	*Maytenus*	*oblongata*	St	EA	98	1	Ko	2	2	2
GO726	Celastraceae	*Maytenus*	*oblongata*	St	M	1	1	Ko	2	2	2
GO726	Celastraceae	*Maytenus*	*oblongata*	St	PE	6	3	Ko	2	2	2
GO726	Celastraceae	*Maytenus*	*oblongata*	St	W	1	1	Ko	2	2	2
GO797	Celastraceae	*Maytenus*	sp.	L and F	EA	32	7	Rg	2	0	2
GO797	Celastraceae	*Maytenus*	sp.	L and F	M	0	0	Rg	2	0	2
GO797	Celastraceae	*Maytenus*	sp.	St	EA	1	1	Rg	2	0	2
GO797	Celastraceae	*Maytenus*	sp.	St	M	0	0	Rg	2	0	2
GO716	Chrysobalanaceae	*Licania*	*affinis*	L	EA	0	0	Ko	2	2	3
GO775	Chrysobalanaceae	*Couepia*	*bracteosa*	L	EA	1	1	Ma	2	0	3
GO775	Chrysobalanaceae	*Couepia*	*bracteosa*	L	M	1	1	Ma	2	0	3
GO775	Chrysobalanaceae	*Couepia*	*bracteosa*	L	PE	2	1	Ma	2	0	3
GO775	Chrysobalanaceae	*Couepia*	*bracteosa*	St	EA	1	1	Ma	2	0	3
GO775	Chrysobalanaceae	*Couepia*	*bracteosa*	St	M	2	1	Ma	2	0	3
GO775	Chrysobalanaceae	*Couepia*	*bracteosa*	St	PE	3	1	Ma	2	0	3
GO716	Chrysobalanaceae	*Licania*	*affinis*	L	M	2	2	Ko	2	2	3
GO716	Chrysobalanaceae	*Licania*	*affinis*	L	PE	97	1	Ko	2	2	3
GO716	Chrysobalanaceae	*Licania*	*affinis*	L	W	1	1	Ko	2	2	3
GO716	Chrysobalanaceae	*Licania*	*affinis*	St	EA	1	1	Ko	2	2	3
GO716	Chrysobalanaceae	*Licania*	*affinis*	St	M	2	2	Ko	2	2	3
GO716	Chrysobalanaceae	*Licania*	*affinis*	St	PE	100	0	Ko	2	2	3
GO716	Chrysobalanaceae	*Licania*	*affinis*	St	W	0	0	Ko	2	2	3

GO798	Clusiaceae	*Clusia*	*palmicida*	L	EA	3	2	Rg	2	0	3
GO798	Clusiaceae	*Clusia*	*palmicida*	L	M	0	0	Rg	2	0	3
GO798	Clusiaceae	*Clusia*	*palmicida*	St	EA	3	2	Rg	2	0	3
GO798	Clusiaceae	*Clusia*	*palmicida*	St	M	3	2	Rg	2	0	3
GO783	Combretaceae	*Terminalia*	*amazonia*	L	EA	1	1	Ma	2	0	2
GO783	Combretaceae	*Terminalia*	*amazonia*	L	M	0	0	Ma	2	0	2
GO783	Combretaceae	*Terminalia*	*amazonia*	B	EA	0	0	Ma	2	0	2
GO783	Combretaceae	*Terminalia*	*amazonia*	B	M	0	0	Ma	2	0	2
GO791	Convolvulaceae	*Ipomea*	*leprieurii*	AP	EA	7	3	Rg	2	0	1
GO791	Convolvulaceae	*Ipomea*	*leprieurii*	AP	M	14	4	Rg	2	0	1
GO791	Convolvulaceae	*Ipomea*	*leprieurii*	AP	PE	3	2	Rg	2	0	1
GO742	Costaceae	*Costus*	*erythrothyrsus*	L	EA	3	1	Si	2	2	1
GO742	Costaceae	*Costus*	*erythrothyrsus*	L	M	3	1	Si	2	2	1
GO742	Costaceae	*Costus*	*erythrothyrsus*	L	PE	13	3	Si	2	2	1
GO742	Costaceae	*Costus*	*erythrothyrsus*	L	W	0	0	Si	2	2	1
GO742	Costaceae	*Costus*	*erythrothyrsus*	St	EA	11	4	Si	2	2	1
GO742	Costaceae	*Costus*	*erythrothyrsus*	St	M	0	0	Si	2	2	1
GO742	Costaceae	*Costus*	*erythrothyrsus*	St	PE	4	2	Si	2	2	1
GO742	Costaceae	*Costus*	*erythrothyrsus*	St	W	0	0	Si	2	2	1
GO742	Costaceae	*Costus*	*erythrothyrsus*	I	EA	100	0	Si	2	2	1
GO742	Costaceae	*Costus*	*erythrothyrsus*	I	M	1	1	Si	2	2	1
GO742	Costaceae	*Costus*	*erythrothyrsus*	I	PE	97	1	Si	2	2	1
GO742	Costaceae	*Costus*	*erythrothyrsus*	I	W	0	0	Si	2	2	1
EH3	Costaceae	*Costus*	cf *spiralis*	I	EA	2	0	Rm	1	2	1
EH4	Costaceae	*Costus*	*spiralis* var. *villosus*	I	EA	0	0	Ko	2	2	1
EH5	Costaceae	*Costus*	*spiralis* var. *villosus*	I	EA	2	0	Ro	1	2	1
GO793	Cyperaceae	*Scleria*	*cyperina*	AP	EA	0	0	Rg	2	0	1
GO793	Cyperaceae	*Scleria*	*cyperina*	AP	M	4	3	Rg	2	0	1
GO781	Dilleniaceae	*Tetracera*	*asperula*	L	EA	2	1	Ma	2	0	1
GO781	Dilleniaceae	*Tetracera*	*asperula*	L	M	1	1	Ma	2	0	1

GO781	Dilleniaceae	*Tetracera*	*asperula*	F	EA	1	1	Ma	2	0	1
GO781	Dilleniaceae	*Tetracera*	*asperula*	F	M	0	0	Ma	2	0	1
GO722	Euphorbiaceae	*Conceveiba*	*guianensis*	L	EA	0	0	Ko	2	2	2
GO722	Euphorbiaceae	*Conceveiba*	*guianensis*	L	M	0	0	Ko	2	2	2
GO722	Euphorbiaceae	*Conceveiba*	*guianensis*	L	PE	12	3	Ko	2	2	2
GO722	Euphorbiaceae	*Conceveiba*	*guianensis*	L	W	0	0	Ko	2	2	2
GO722	Euphorbiaceae	*Conceveiba*	*guianensis*	St	EA	0	0	Ko	2	2	2
GO722	Euphorbiaceae	*Conceveiba*	*guianensis*	St	M	1	1	Ko	2	2	2
GO722	Euphorbiaceae	*Conceveiba*	*guianensis*	St	PE	8	2	Ko	2	2	2
GO722	Euphorbiaceae	*Conceveiba*	*guianensis*	St	W	0	0	Ko	2	2	2
GO790	Euphorbiaceae	*Cnidoscolus*	*urens*	AP	EA	1	1	Mc	2	1	1
GO790	Euphorbiaceae	*Cnidoscolus*	*urens*	AP	M	0	0	Mc	2	1	1
GO786	Euphorbiaceae	*Croton*	*guianensis*	L	EA	2	1	Ma	2	1	2
GO786	Euphorbiaceae	*Croton*	*guianensis*	L	M	3	2	Ma	2	1	2
VE202	Euphorbiaceae	*Croton*	*macradenis*	AP	EA	2	2	Mo	2	1	0
VE202	Euphorbiaceae	*Croton*	*macradenis*	AP	M	0	0	Mo	2	1	0
VE202	Euphorbiaceae	*Croton*	*macradenis*	AP	PE	54	4	Mo	2	1	0
VE202	Euphorbiaceae	*Croton*	*macradenis*	AP	W	3	1	Mo	2	1	0
VE167	Euphorbiaceae	*Croton*	*matourensis*	L	EA	0	0	Mt	2	1	2
VE167	Euphorbiaceae	*Croton*	*matourensis*	L	M	4	2	Mt	2	1	2
VE167	Euphorbiaceae	*Croton*	*matourensis*	L	PE	0	0	Mt	2	1	2
VE167	Euphorbiaceae	*Croton*	*matourensis*	L	W	0	0	Mt	2	1	2
VE167	Euphorbiaceae	*Croton*	*matourensis*	B	EA	1	1	Mt	2	1	2
VE167	Euphorbiaceae	*Croton*	*matourensis*	B	M	2	1	Mt	2	1	2
VE167	Euphorbiaceae	*Croton*	*matourensis*	B	PE	2	1	Mt	2	1	2
VE167	Euphorbiaceae	*Croton*	*matourensis*	B	W	0	0	Mt	2	1	2
GO743	Euphorbiaceae	*Croton*	*nuntians*	L	EA	1	1	Si	2	2	1
GO743	Euphorbiaceae	*Croton*	*nuntians*	L	M	2	1	Si	2	2	1
GO743	Euphorbiaceae	*Croton*	*nuntians*	L	PE	1	1	Si	2	2	1
GO743	Euphorbiaceae	*Croton*	*nuntians*	L	W	1	1	Si	2	2	1

GO743	Euphorbiaceae	*Croton*	*nuntians*	St	EA	6	1	Si	2	2	1
GO743	Euphorbiaceae	*Croton*	*nuntians*	St	M	0	0	Si	2	2	1
GO743	Euphorbiaceae	*Croton*	*nuntians*	St	PE	3	1	Si	2	2	1
GO743	Euphorbiaceae	*Croton*	*nuntians*	St	W	0	0	Si	2	2	1
VE199	Euphorbiaceae	*Croton*	*nuntians*	L	EA	2	1	Si	2	2	1
VE199	Euphorbiaceae	*Croton*	*nuntians*	L	M	2	1	Si	2	2	1
VE199	Euphorbiaceae	*Croton*	*nuntians*	L	PE	3	2	Si	2	2	1
VE199	Euphorbiaceae	*Croton*	*nuntians*	L	W	0	0	Si	2	2	1
VE199	Euphorbiaceae	*Croton*	*nuntians*	St	EA	1	1	Si	2	2	1
VE199	Euphorbiaceae	*Croton*	*nuntians*	St	M	0	0	Si	2	2	1
VE199	Euphorbiaceae	*Croton*	*nuntians*	St	PE	4	2	Si	2	2	1
VE199	Euphorbiaceae	*Croton*	*nuntians*	St	W	1	1	Si	2	2	1
GO794	Euphorbiaceae	*Sapium*	*argutum*	L	EA	8	4	Rg	2	0	2
GO794	Euphorbiaceae	*Sapium*	*argutum*	L	M	0	0	Rg	2	0	2
GO794	Euphorbiaceae	*Sapium*	*argutum*	St	EA	0	0	Rg	2	0	2
GO794	Euphorbiaceae	*Sapium*	*argutum*	St	M	0	0	Rg	2	0	2
GO719	Fabaceae	*Alexa*	*wachenheimii*	L	EA	0	0	Ko	2	2	3
GO719	Fabaceae	*Alexa*	*wachenheimii*	L	M	0	0	Ko	2	2	3
GO719	Fabaceae	*Alexa*	*wachenheimii*	L	PE	5	1	Ko	2	2	3
GO719	Fabaceae	*Alexa*	*wachenheimii*	L	W	0	0	Ko	2	2	3
GO719	Fabaceae	*Alexa*	*wachenheimii*	B	EA	6	3	Ko	2	2	3
GO719	Fabaceae	*Alexa*	*wachenheimii*	B	M	1	1	Ko	2	2	3
GO719	Fabaceae	*Alexa*	*wachenheimii*	B	PE	56	3	Ko	2	2	3
GO719	Fabaceae	*Alexa*	*wachenheimii*	B	W	0	0	Ko	2	2	3
238	Fabaceae	*Bocoa*	*prouacensis*	B	EA	3	2	Si	0	2	3
238	Fabaceae	*Bocoa*	*prouacensis*	B	M	1	1	Si	0	2	3
238	Fabaceae	*Bocoa*	*prouacensis*	B	PE	0	0	Si	0	2	3
238	Fabaceae	*Bocoa*	*prouacensis*	B	W	0	0	Si	0	2	3
GO806	Fabaceae	*Chamaecrista*	*desvauxii* var. *saxatilis*	AP	EA	4	2	Rg	2	0	1
GO806	Fabaceae	*Chamaecrista*	*desvauxii* var. *saxatilis*	AP	M	0	0	Rg	2	0	1

GO758	Fabaceae	*Chamaecrista*	*diphylla*	AP	EA	4	0	Mc	2	1	0
GO758	Fabaceae	*Chamaecrista*	*diphylla*	AP	M	0	0	Mc	2	1	0
GO758	Fabaceae	*Chamaecrista*	*diphylla*	AP	PE	1	1	Mc	2	1	0
GO758	Fabaceae	*Chamaecrista*	*diphylla*	AP	W	0	0	Mc	2	1	0
GO762	Fabaceae	*Dalbergia*	*monetaria*	L	EA	0	0	Mc	2	0	0
GO762	Fabaceae	*Dalbergia*	*monetaria*	L	M	1	1	Mc	2	0	0
GO762	Fabaceae	*Dalbergia*	*monetaria*	L	PE	2	1	Mc	2	0	0
GO762	Fabaceae	*Dalbergia*	*monetaria*	L	W	1	1	Mc	2	0	0
GO762	Fabaceae	*Dalbergia*	*monetaria*	St	EA	1	1	Mc	2	0	0
GO762	Fabaceae	*Dalbergia*	*monetaria*	St	M	0	0	Mc	2	0	0
GO762	Fabaceae	*Dalbergia*	*monetaria*	St	PE	2	1	Mc	2	0	0
GO762	Fabaceae	*Dalbergia*	*monetaria*	St	W	0	0	Mc	2	0	0
GO746	Fabaceae	*Desmodium*	*barbatum*	WP	EA	2	1	Si	2	0	0
GO746	Fabaceae	*Desmodium*	*barbatum*	WP	M	0	0	Si	2	0	0
GO746	Fabaceae	*Desmodium*	*barbatum*	WP	PE	3	2	Si	2	0	0
GO746	Fabaceae	*Desmodium*	*barbatum*	WP	W	0	0	Si	2	0	0
GO779	Fabaceae	*Dimorphandra*	*polyandra*	L	EA	5	5	Ma	2	0	3
GO779	Fabaceae	*Dimorphandra*	*polyandra*	L	M	1	1	Ma	2	0	3
GO779	Fabaceae	*Dimorphandra*	*polyandra*	B	EA	4	2	Ma	2	0	3
GO779	Fabaceae	*Dimorphandra*	*polyandra*	B	M	0	0	Ma	2	0	3
GO759	Fabaceae	*Entada*	*polystachya*	L	EA	0	0	Mc	2	1	1
GO759	Fabaceae	*Entada*	*polystachya*	L	M	0	0	Mc	2	1	1
GO759	Fabaceae	*Entada*	*polystachya*	L	PE	2	1	Mc	2	1	1
GO759	Fabaceae	*Entada*	*polystachya*	L	W	0	0	Mc	2	1	1
GO759	Fabaceae	*Entada*	*polystachya*	St	EA	2	1	Mc	2	1	1
GO759	Fabaceae	*Entada*	*polystachya*	St	M	1	1	Mc	2	1	1
GO759	Fabaceae	*Entada*	*polystachya*	St	W	0	0	Mc	2	1	1
PMF4976	Fabaceae	*Enterolobium*	*schomburgkii*	W	EA	1	1	Si	0	2	3
PMF4976	Fabaceae	*Enterolobium*	*schomburgkii*	W	M	13	2	Si	0	2	3
PMF4976	Fabaceae	*Enterolobium*	*schomburgkii*	W	W	2	1	Si	0	2	3

PMF4976	Fabaceae	*Enterolobium*	*schomburgkii*	B	EA	1	1	Si	0	2	3
PMF4976	Fabaceae	*Enterolobium*	*schomburgkii*	B	M	2	2	Si	0	2	3
PMF4976	Fabaceae	*Enterolobium*	*schomburgkii*	B	PE	0	0	Si	0	2	3
PMF4976	Fabaceae	*Enterolobium*	*schomburgkii*	B	W	2	1	Si	0	2	3
MC1129	Fabaceae	*Inga*	*alba*	W	EA	3	1	Si	0	2	3
MC1129	Fabaceae	*Inga*	*alba*	W	M	5	1	Si	0	2	3
MC1129	Fabaceae	*Inga*	*alba*	W	W	1	1	Si	0	2	3
GO805	Fabaceae	*Inga*	*virgultosa*	L	EA	0	0	Rg	2	0	3
GO805	Fabaceae	*Inga*	*virgultosa*	L	M	0	0	Rg	2	0	3
GO805	Fabaceae	*Inga*	*virgultosa*	St	EA	1	1	Rg	2	0	3
GO805	Fabaceae	*Inga*	*virgultosa*	St	M	0	0	Rg	2	0	3
VE108B	Fabaceae	*Lonchocarpus*	*monilis*	L	EA	100	0	Mo	2	1	2
VE108B	Fabaceae	*Lonchocarpus*	*monilis*	L	M	97	2	Mo	2	1	2
VE108B	Fabaceae	*Lonchocarpus*	*monilis*	L	PE	100	0	Mo	2	1	2
VE108B	Fabaceae	*Lonchocarpus*	*monilis*	L	W	19	1	Mo	2	1	2
GO725	Fabaceae	*Macrolobium*	*bifolium*	L	EA	1	1	Ko	2	2	3
GO725	Fabaceae	*Macrolobium*	*bifolium*	L	M	1	1	Ko	2	2	3
GO725	Fabaceae	*Macrolobium*	*bifolium*	L	PE	8	2	Ko	2	2	3
GO725	Fabaceae	*Macrolobium*	*bifolium*	L	W	0	0	Ko	2	2	3
GO725	Fabaceae	*Macrolobium*	*bifolium*	St	EA	0	0	Ko	2	2	3
GO725	Fabaceae	*Macrolobium*	*bifolium*	St	M	1	1	Ko	2	2	3
GO725	Fabaceae	*Macrolobium*	*bifolium*	St	PE	3	1	Ko	2	2	3
GO725	Fabaceae	*Macrolobium*	*bifolium*	St	W	0	0	Ko	2	2	3
GO785	Fabaceae	*Macrolobium*	*guianense*	L	EA	0	0	Ma	0	2	3
GO785	Fabaceae	*Macrolobium*	*guianense*	L	M	0	0	Ma	0	2	3
GO785	Fabaceae	*Macrolobium*	*guianense*	W	EA	1	1	Ma	0	2	3
GO785	Fabaceae	*Macrolobium*	*guianense*	W	M	0	0	Ma	0	2	3
GO717	Fabaceae	*Ormosia*	*coutinhoi*	L	EA	2	1	Ko	2	2	2
GO717	Fabaceae	*Ormosia*	*coutinhoi*	L	M	1	1	Ko	2	2	2
GO717	Fabaceae	*Ormosia*	*coutinhoi*	L	PE	14	5	Ko	2	2	2

GO717	Fabaceae	*Ormosia*	*coutinhoi*	L	W	0	0	Ko	2	2	2
GO717	Fabaceae	*Ormosia*	*coutinhoi*	St	EA	1	1	Ko	2	2	2
GO717	Fabaceae	*Ormosia*	*coutinhoi*	St	M	2	1	Ko	2	2	2
GO717	Fabaceae	*Ormosia*	*coutinhoi*	St	PE	6	2	Ko	2	2	2
GO717	Fabaceae	*Ormosia*	*coutinhoi*	St	W	0	0	Ko	2	2	2
GO738	Fabaceae	*Senna*	*quinquangulata*	L	EA	4	2	Si	2	2	1
GO738	Fabaceae	*Senna*	*quinquangulata*	L	M	4	3	Si	2	2	1
GO738	Fabaceae	*Senna*	*quinquangulata*	L	PE	10	3	Si	2	2	1
GO738	Fabaceae	*Senna*	*quinquangulata*	L	W	0	0	Si	2	2	1
GO738	Fabaceae	*Senna*	*quinquangulata*	St	EA	2	1	Si	2	2	1
GO738	Fabaceae	*Senna*	*quinquangulata*	St	M	0	0	Si	2	2	1
GO738	Fabaceae	*Senna*	*quinquangulata*	St	PE	7	3	Si	2	2	1
GO738	Fabaceae	*Senna*	*quinquangulata*	St	W	1	1	Si	2	2	1
VE137	Fabaceae	*Spirotropis*	*longifolia*	W	EA	3	2	Si	0	2	3
VE137	Fabaceae	*Spirotropis*	*longifolia*	W	M	0	0	Si	0	2	3
VE137	Fabaceae	*Spirotropis*	*longifolia*	W	PE	16	4	Si	0	2	3
VE137	Fabaceae	*Spirotropis*	*longifolia*	W	W	0	0	Si	0	2	3
VE137	Fabaceae	*Spirotropis*	*longifolia*	B	EA	0	0	Si	0	2	3
VE137	Fabaceae	*Spirotropis*	*longifolia*	B	M	0	0	Si	0	2	3
VE137	Fabaceae	*Spirotropis*	*longifolia*	B	PE	3	2	Si	0	2	3
VE137	Fabaceae	*Spirotropis*	*longifolia*	B	W	0	0	Si	0	2	3
VE137	Fabaceae	*Spirotropis*	*longifolia*	Roots	EA	2	1	Si	0	2	3
VE137	Fabaceae	*Spirotropis*	*longifolia*	Roots	M	0	0	Si	0	2	3
VE137	Fabaceae	*Spirotropis*	*longifolia*	Roots	PE	13	3	Si	0	2	3
VE137	Fabaceae	*Spirotropis*	*longifolia*	Roots	W	3	1	Si	0	2	3
GO792	Fabaceae	*Stylosanthes*	*guianensis*	AP	EA	3	2	Rg	2	0	1
GO792	Fabaceae	*Stylosanthes*	*guianensis*	AP	M	1	1	Rg	2	0	1
GO715	Fabaceae	*Swartzia*	*guianensis*	L	EA	1	1	Ko	2	2	2
GO715	Fabaceae	*Swartzia*	*guianensis*	L	M	4	2	Ko	2	2	2
GO715	Fabaceae	*Swartzia*	*guianensis*	L	PE	0	0	Ko	2	2	2

GO715	Fabaceae	*Swartzia*	*guianensis*	L	W	0	0	Ko	2	2	2
GO715	Fabaceae	*Swartzia*	*guianensis*	St	EA	3	1	Ko	2	2	2
GO715	Fabaceae	*Swartzia*	*guianensis*	St	M	0	0	Ko	2	2	2
GO715	Fabaceae	*Swartzia*	*guianensis*	St	PE	10	2	Ko	2	2	2
GO715	Fabaceae	*Swartzia*	*guianensis*	St	W	0	0	Ko	2	2	2
GO764	Fabaceae	*Vigna*	*luteola*	AP	EA	0	0	Mc	2	0	1
GO764	Fabaceae	*Vigna*	*luteola*	AP	M	5	1	Mc	2	0	1
GO764	Fabaceae	*Vigna*	*luteola*	AP	PE	2	1	Mc	2	0	1
GO784	Humiriaceae	*Humiria*	*balsamifera*	B	EA	84	4	Ma	1	0	3
GO784	Humiriaceae	*Humiria*	*balsamifera*	B	M	16	3	Ma	1	0	3
VE101	Humiriaceae	*Humiria*	*balsamifera*	W	EA	0	0	Mc	1	1	2
VE101	Humiriaceae	*Humiria*	*balsamifera*	W	M	2	1	Mc	1	1	2
VE101	Humiriaceae	*Humiria*	*balsamifera*	W	PE	6	1	Mc	1	1	2
VE101	Humiriaceae	*Humiria*	*balsamifera*	W	W	1	1	Mc	1	1	2
PS16	Lauraceae	*Licaria*	*cannella*	W	EA	6	3	Rg	0	2	3
PS16	Lauraceae	*Licaria*	*cannella*	W	M	0	0	Rg	0	2	3
PS16	Lauraceae	*Licaria*	*cannella*	W	PE	20	2	Rg	0	2	3
PS16	Lauraceae	*Licaria*	*cannella*	W	W	0	0	Rg	0	2	3
1039	Lauraceae	*Sextonia*	*rubra*	B	EA	100	0	Si	0	2	3
AR12	Lauraceae	*Sextonia*	*rubra*	W	M	100	0	Rg	0	2	3
GO720	Loranthaceae	*Phthirusa*	sp.	L	EA	0	0	Ko	2	2	2
GO720	Loranthaceae	*Phthirusa*	sp.	L	M	0	0	Ko	2	2	2
GO720	Loranthaceae	*Phthirusa*	sp.	L	PE	5	1	Ko	2	2	2
GO720	Loranthaceae	*Phthirusa*	sp.	L	W	0	0	Ko	2	2	2
GO720	Loranthaceae	*Phthirusa*	sp.	St	EA	1	1	Ko	2	2	2
GO720	Loranthaceae	*Phthirusa*	sp.	St	M	1	1	Ko	2	2	2
GO720	Loranthaceae	*Phthirusa*	sp.	St	PE	1	1	Ko	2	2	2
GO796	Lythraceae	*Cuphea*	*blackii*	AP	EA	0	0	Rg	2	0	1
GO796	Lythraceae	*Cuphea*	*blackii*	AP	M	0	0	Rg	2	0	1
GO755	Malpighiaceae	*Byrsonima*	*crassifolia*	L	EA	4	0	Mc	2	1	2

GO780	Malpighiaceae	*Byrsonima*	*aerugo*	L	EA	2	1	Ma	2	0	2
GO780	Malpighiaceae	*Byrsonima*	*aerugo*	L	M	0	0	Ma	2	0	2
GO755	Malpighiaceae	*Byrsonima*	*crassifolia*	L	M	1	1	Mc	2	1	2
GO755	Malpighiaceae	*Byrsonima*	*crassifolia*	L	PE	1	1	Mc	2	1	2
GO755	Malpighiaceae	*Byrsonima*	*crassifolia*	L	W	0	0	Mc	2	1	2
GO755	Malpighiaceae	*Byrsonima*	*crassifolia*	B	EA	1	1	Mc	2	1	2
GO755	Malpighiaceae	*Byrsonima*	*crassifolia*	B	M	1	1	Mc	2	1	2
GO755	Malpighiaceae	*Byrsonima*	*crassifolia*	B	PE	2	2	Mc	2	1	2
GO755	Malpighiaceae	*Byrsonima*	*crassifolia*	B	W	0	0	Mc	2	1	2
GO754	Malpighiaceae	*Byrsonima*	*spicata*	L	EA	0	0	Mc	1	1	2
GO754	Malpighiaceae	*Byrsonima*	*spicata*	L	M	0	0	Mc	1	1	2
GO754	Malpighiaceae	*Byrsonima*	*spicata*	L	PE	6	3	Mc	1	1	2
GO754	Malpighiaceae	*Byrsonima*	*spicata*	L	W	0	0	Mc	1	1	2
GO754	Malpighiaceae	*Byrsonima*	*spicata*	W	EA	3	1	Mc	1	1	2
GO754	Malpighiaceae	*Byrsonima*	*spicata*	W	M	0	0	Mc	1	1	2
GO754	Malpighiaceae	*Byrsonima*	*spicata*	W	PE	2	1	Mc	1	1	2
GO754	Malpighiaceae	*Byrsonima*	*spicata*	W	W	0	0	Mc	1	1	2
GO754	Malpighiaceae	*Byrsonima*	*spicata*	B	EA	4	2	Mc	1	1	2
GO754	Malpighiaceae	*Byrsonima*	*spicata*	B	M	2	1	Mc	1	1	2
GO754	Malpighiaceae	*Byrsonima*	*spicata*	B	PE	1	1	Mc	1	1	2
GO754	Malpighiaceae	*Byrsonima*	*spicata*	B	W	1	1	Mc	1	1	2
GO801	Malvaceae	*Eriotheca*	*surinamensis*	L	EA	1	1	Rg	2	0	3
GO801	Malvaceae	*Eriotheca*	*surinamensis*	L	M	1	1	Rg	2	0	3
1058	Malvaceae	*Sterculia*	*pruriens*	B	EA	0	0	Si	0	2	3
1058	Malvaceae	*Sterculia*	*pruriens*	B	M	0	0	Si	0	2	3
1058	Malvaceae	*Sterculia*	*pruriens*	B	PE	1	1	Si	0	2	3
1058	Malvaceae	*Sterculia*	*pruriens*	B	W	1	1	Si	0	2	3
GO804	Melastomataceae	*Ernestia*	*granvillei*	AP	EA	2	2	Rg	2	0	1
GO804	Melastomataceae	*Ernestia*	*granvillei*	AP	M	0	0	Rg	2	0	1
GO712	Meliaceae	*Azadirachta*	*indica*	L	M	2	0	Ko	1	2	2

GO756	Meliaceae	*Guarea*	*guidonia*	L	EA	3	1	Mc	2	1	2
GO756	Meliaceae	*Guarea*	*guidonia*	L	M	0	0	Mc	2	1	2
GO756	Meliaceae	*Guarea*	*guidonia*	L	PE	0	0	Mc	2	1	2
GO756	Meliaceae	*Guarea*	*guidonia*	L	W	0	0	Mc	2	1	2
GO756	Meliaceae	*Guarea*	*guidonia*	St	EA	2	1	Mc	2	1	2
GO756	Meliaceae	*Guarea*	*guidonia*	St	M	1	1	Mc	2	1	2
GO756	Meliaceae	*Guarea*	*guidonia*	St	PE	0	0	Mc	2	1	2
GO756	Meliaceae	*Guarea*	*guidonia*	St	W	1	1	Mc	2	1	2
BC	Moraceae	*Bagassa*	*guianensis*	B	EA	1	1	Si	1	1	3
BC	Moraceae	*Bagassa*	*guianensis*	B	M	0	0	Si	1	1	3
GO799	Myrtaceae	*Myrcia*	*saxatilis*	L	EA	0	0	Rg	2	0	2
GO799	Myrtaceae	*Myrcia*	*saxatilis*	L	M	1	1	Rg	2	0	2
GO799	Myrtaceae	*Myrcia*	*saxatilis*	St	EA	3	2	Rg	2	0	2
GO799	Myrtaceae	*Myrcia*	*saxatilis*	St	M	2	2	Rg	2	0	2
GO757	Orobanchaceae	*Anisantherina*	*hispidula*	WP	EA	2	1	Mc	2	1	2
GO757	Orobanchaceae	*Anisantherina*	*hispidula*	WP	M	0	0	Mc	2	1	2
GO757	Orobanchaceae	*Anisantherina*	*hispidula*	WP	PE	0	0	Mc	2	1	2
GO757	Orobanchaceae	*Anisantherina*	*hispidula*	WP	W	0	0	Mc	2	1	2
GO741	Piperaceae	*Piper*	*hispidum*	L	EA	62	5	Si	2	1	1
GO741	Piperaceae	*Piper*	*hispidum*	L	M	1	1	Si	2	1	1
GO741	Piperaceae	*Piper*	*hispidum*	L	PE	3	2	Si	2	1	1
GO741	Piperaceae	*Piper*	*hispidum*	L	W	0	0	Si	2	1	1
GO741	Piperaceae	*Piper*	*hispidum*	St	EA	3	1	Si	2	1	1
GO741	Piperaceae	*Piper*	*hispidum*	St	M	0	0	Si	2	1	1
GO741	Piperaceae	*Piper*	*hispidum*	St	PE	39	10	Si	2	1	1
GO741	Piperaceae	*Piper*	*hispidum*	St	W	0	0	Si	2	1	1
GO787	Polygalaceae	*Polygala*	*longicaulis*	WP	EA	2	1	Ma	2	0	0
GO787	Polygalaceae	*Polygala*	*longicaulis*	WP	M	0	0	Ma	2	0	0
GO723	Rubiaceae	*Posoqueria*	*longifolia*	L	EA	0	0	Ko	2	2	2
GO723	Rubiaceae	*Posoqueria*	*longifolia*	L	M	0	0	Ko	2	2	2

GO723	Rubiaceae	*Posoqueria*	*longifolia*	L	PE	10	2	Ko	2	2	2
GO723	Rubiaceae	*Posoqueria*	*longifolia*	L	W	0	0	Ko	2	2	2
GO803	Rubiaceae	*Sipanea*	*pratensis*	AP	EA	3	2	Rg	2	0	0
GO803	Rubiaceae	*Sipanea*	*pratensis*	AP	M	0	0	Rg	2	0	0
GO802	Rubiaceae	*Tocoyena*	*guianensis*	AP	EA	1	1	Rg	2	0	2
GO802	Rubiaceae	*Tocoyena*	*guianensis*	AP	M	1	1	Rg	2	0	2
GO748	Salicaceae	*Banara*	*guianensis*	L	EA	1	1	Si	2	1	1
GO748	Salicaceae	*Banara*	*guianensis*	L	M	0	0	Si	2	1	1
GO748	Salicaceae	*Banara*	*guianensis*	L	PE	8	2	Si	2	1	1
GO748	Salicaceae	*Banara*	*guianensis*	L	W	0	0	Si	2	1	1
GO748	Salicaceae	*Banara*	*guianensis*	St	EA	2	2	Si	2	1	1
GO748	Salicaceae	*Banara*	*guianensis*	St	M	0	0	Si	2	1	1
GO748	Salicaceae	*Banara*	*guianensis*	St	W	0	0	Si	2	1	1
GO777	Salicaceae	*Casearia*	*grandiflora*	L	EA	8	4	Ma	2	0	3
GO777	Salicaceae	*Casearia*	*grandiflora*	L	M	0	0	Ma	2	0	3
GO777	Salicaceae	*Casearia*	*grandiflora*	L	PE	4	0	Ma	2	0	3
GO777	Salicaceae	*Casearia*	*grandiflora*	W	EA	1	1	Ma	2	0	3
GO777	Salicaceae	*Casearia*	*grandiflora*	W	M	1	1	Ma	2	0	3
GO777	Salicaceae	*Casearia*	*grandiflora*	B	EA	5	3	Ma	2	0	3
GO777	Salicaceae	*Casearia*	*grandiflora*	B	M	3	1	Ma	2	0	3
GO777	Salicaceae	*Casearia*	*grandiflora*	B	PE	11	2	Ma	2	0	3
GO771	Salicaceae	*Laetia*	*procera*	B	EA	14	3	Mc	1	1	3
424	Salicaceae	*Laetia*	*procera*	B	EA	28	3	Si	0	2	3
424	Salicaceae	*Laetia*	*procera*	B	M	21	4	Si	0	2	3
1003	Salicaceae	*Laetia*	*procera*	B	EA	63	6	Si	0	2	3
1003	Salicaceae	*Laetia*	*procera*	B	M	0	0	Si	0	2	3
1003	Salicaceae	*Laetia*	*procera*	B	PE	94	2	Si	0	2	3
1003	Salicaceae	*Laetia*	*procera*	B	W	6	3	Si	0	2	3
GO778	Sapindaceae	*Cupania*	*scrobiculata*	L	EA	2	2	Ma	2	0	3
GO778	Sapindaceae	*Cupania*	*scrobiculata*	L	M	3	2	Ma	2	0	3

GO778	Sapindaceae	*Cupania*	*scrobiculata*	F	EA	64	2	Ma	2	0	3
GO778	Sapindaceae	*Cupania*	*scrobiculata*	F	M	0	0	Ma	2	0	3
GO778	Sapindaceae	*Cupania*	*scrobiculata*	St	EA	3	2	Ma	2	0	3
GO778	Sapindaceae	*Cupania*	*scrobiculata*	St	M	1	1	Ma	2	0	3
GO776	Sapindaceae	*Matayba*	*arborescens*	L	EA	14	5	Ma	2	0	3
GO776	Sapindaceae	*Matayba*	*arborescens*	L	M	2	1	Ma	2	0	3
GO776	Sapindaceae	*Matayba*	*arborescens*	L	PE	4	0	Ma	2	0	3
GO776	Sapindaceae	*Matayba*	*arborescens*	F	EA	60	3	Ma	2	0	3
GO776	Sapindaceae	*Matayba*	*arborescens*	F	M	1	1	Ma	2	0	3
GO776	Sapindaceae	*Matayba*	*arborescens*	F	PE	51	7	Ma	2	0	3
GO776	Sapindaceae	*Matayba*	*arborescens*	St	EA	31	6	Ma	2	0	3
GO776	Sapindaceae	*Matayba*	*arborescens*	St	M	2	1	Ma	2	0	3
GO776	Sapindaceae	*Matayba*	*arborescens*	St	PE	24	5	Ma	2	0	3
GO713	Sapindaceae	*Paullinia*	sp.	L	EA	0	0	Si	2	2	2
GO713	Sapindaceae	*Paullinia*	sp.	L	M	0	0	Si	2	2	2
GO713	Sapindaceae	*Paullinia*	sp.	L	PE	3	1	Si	2	2	2
GO713	Sapindaceae	*Paullinia*	sp.	L	W	1	1	Si	2	2	2
GO713	Sapindaceae	*Paullinia*	sp.	St	EA	0	0	Si	2	2	2
GO713	Sapindaceae	*Paullinia*	sp.	St	M	0	0	Si	2	2	2
GO713	Sapindaceae	*Paullinia*	sp.	St	PE	1	1	Si	2	2	2
GO713	Sapindaceae	*Paullinia*	sp.	St	W	0	0	Si	2	2	2
GO763	Sapindaceae	*Paullinia*	*pinnata*	AP	EA	9	3	Mc	2	0	1
GO763	Sapindaceae	*Paullinia*	*pinnata*	AP	M	0	0	Mc	2	0	1
GO763	Sapindaceae	*Paullinia*	*pinnata*	AP	PE	2	1	Mc	2	0	1
RB1904	Sapotaceae	*Manilkara*	*huberi*	W	EA	2	1	Si	0	2	3
RB1904	Sapotaceae	*Manilkara*	*huberi*	W	M	2	1	Si	0	2	3
RB1904	Sapotaceae	*Manilkara*	*huberi*	W	PE	11	1	Si	0	2	3
RB1904	Sapotaceae	*Manilkara*	*huberi*	W	W	0	0	Si	0	2	3
RB1904	Sapotaceae	*Manilkara*	*huberi*	B	EA	2	2	Si	0	2	3
RB1904	Sapotaceae	*Manilkara*	*huberi*	B	M	1	1	Si	0	2	3

RB1904	Sapotaceae	*Manilkara*	*huberi*	B	PE	7	2	Si	0	2	3
RB1904	Sapotaceae	*Manilkara*	*huberi*	B	W	1	1	Si	0	2	3
GO714	Simaroubaceae	*Quassia*	*amara*	St	EA	8	1	Rm	0	2	2
GO747	Siparunaceae	*Siparuna*	*guianensis*	L	EA	0	0	Si	2	1	1
GO747	Siparunaceae	*Siparuna*	*guianensis*	L	M	0	0	Si	2	1	1
GO747	Siparunaceae	*Siparuna*	*guianensis*	L	PE	1	1	Si	2	1	1
GO747	Siparunaceae	*Siparuna*	*guianensis*	L	W	0	0	Si	2	1	1
GO747	Siparunaceae	*Siparuna*	*guianensis*	St	EA	5	2	Si	2	1	1
GO747	Siparunaceae	*Siparuna*	*guianensis*	St	M	0	0	Si	2	1	1
GO747	Siparunaceae	*Siparuna*	*guianensis*	St	PE	2	1	Si	2	1	1
GO747	Siparunaceae	*Siparuna*	*guianensis*	St	W	0	0	Si	2	1	1
GO761	Solanaceae	*Cestrum*	*latifolium*	L	EA	39	3	Mc	2	0	1
GO761	Solanaceae	*Cestrum*	*latifolium*	L	M	20	3	Mc	2	0	1
GO761	Solanaceae	*Cestrum*	*latifolium*	L	PE	1	1	Mc	2	0	1
GO761	Solanaceae	*Cestrum*	*latifolium*	L	W	0	0	Mc	2	0	1
GO761	Solanaceae	*Cestrum*	*latifolium*	St	EA	58	11	Mc	2	0	1
GO761	Solanaceae	*Cestrum*	*latifolium*	St	M	0	0	Mc	2	0	1
GO761	Solanaceae	*Cestrum*	*latifolium*	St	PE	15	2	Mc	2	0	1
GO761	Solanaceae	*Cestrum*	*latifolium*	St	W	0	0	Mc	2	0	1
GO740	Solanaceae	*Solanum*	*leucocarpon*	L	EA	0	0	Si	2	1	2
GO740	Solanaceae	*Solanum*	*leucocarpon*	L	M	1	1	Si	2	1	2
GO740	Solanaceae	*Solanum*	*leucocarpon*	L	PE	11	4	Si	2	1	2
GO740	Solanaceae	*Solanum*	*leucocarpon*	L	W	0	0	Si	2	1	2
GO740	Solanaceae	*Solanum*	*leucocarpon*	St	EA	0	0	Si	2	1	2
GO740	Solanaceae	*Solanum*	*leucocarpon*	St	M	5	1	Si	2	1	2
GO740	Solanaceae	*Solanum*	*leucocarpon*	St	PE	3	2	Si	2	1	2
GO740	Solanaceae	*Solanum*	*leucocarpon*	St	W	0	0	Si	2	1	2
GO751	Solanaceae	*Solanum*	*stramoniifolium*	AP	EA	3	2	Si	2	1	0
GO751	Solanaceae	*Solanum*	*stramoniifolium*	AP	M	0	0	Si	2	1	0
GO751	Solanaceae	*Solanum*	*stramoniifolium*	AP	PE	4	2	Si	2	1	0

GO751	Solanaceae	*Solanum*	*stramoniifolium*	AP	W	1	1	Si	2	1	0
GO752	Solanaceae	*Solanum*	*subinerme*	AP	EA	6	1	Si	2	1	0
GO752	Solanaceae	*Solanum*	*subinerme*	AP	M	0	0	Si	2	1	0
GO752	Solanaceae	*Solanum*	*subinerme*	AP	PE	1	1	Si	2	1	0
GO752	Solanaceae	*Solanum*	*subinerme*	AP	W	0	0	Si	2	1	0
514	Vochysiaceae	*Erisma*	*uncinatum*	B	EA	0	0	Si	0	2	3
514	Vochysiaceae	*Erisma*	*uncinatum*	B	M	0	0	Si	0	2	3
514	Vochysiaceae	*Erisma*	*uncinatum*	B	PE	2	1	Si	0	2	3
514	Vochysiaceae	*Erisma*	*uncinatum*	B	W	0	0	Si	0	2	3

[a] Voucher number at Cayenne Herbarium (CAY) or tree number from a permanent plot in Sinnamary or tree identifies by forest prospectors (BC)

[b] B: bark, W: wood, St: stems, R: roots, L: leaves, AP: aerial parts, WP: whole plant, I: inflorescence, F: fruits

[c] W: water. PE: petroleum ether. M: methanol. EA: ethyl acetate

[d] Standard deviation

[e] Si: Sinnamary. Mo: Montsinéry-Tonnegrande. Rg: Régina. Mc: Macouria, Ma: Mana. Ko: Kourou. Mt: Matoury. Rm: Rémire-Montjoly. Ro: Roura

[f] Temporary vegetation: 0, secondary / low or slightly ligneous vegetation: 1, ligneous species: 2, large trees: 3

Table S2 Full dataset of Tukey HSD pairwise differences between variables

	CI 95%			
	Differences	**Lower**	**Upper**	**P-value**
Solvents [a]				
M - EA	-0.3564242	-0.6220793	-0.09076897	0.0033256
PE - EA	0.2273556	-0.0720787	0.52678993	0.2054870
W - EA	-0.4794681	-0.7877130	-0.17122314	0.0004155
PE - M	0.5837798	0.2826667	0.88489285	0.0000051
W -M	-0.1230439	-0.4329198	0.18683205	0.7352206
W -PE	-0.7068237	-1.0461043	-0.36754305	0.0000008
Organs				
Bark-Aerial parts	0.30846280	-0.20425632	0.821181914	0.6593495
Fruits-Aerial parts	1.17136950	0.06659874	2.276140254	0.0277396
Inflorescence-Aerial parts	1.33354457	0.22877381	2.438315322	0.0055035
Leaves-Aerial parts	0.13294164	-0.30847814	0.574361423	0.9942709
Leaves and fruits-Aerial parts	0.72096847	-1.25477307	2.696710000	0.9776100
Roots-Aerial parts	0.06533190	-1.35784387	1.488507670	1.0000000
Stems-Aerial parts	0.09981891	-0.36192028	0.561558101	0.9995720
Whole plant-Aerial parts	0.25682463	-0.59475547	1.108404731	0.9942117
Wood-Aerial parts	0.21014143	-0.41407223	0.834355098	0.9871663
Fruits-Bark	0.86290670	-0.22741042	1.953223818	0.2619128
Inflorescence-Bark	1.02508177	-0.06523535	2.115398886	0.0856270
Leaves-Bark	-0.17552116	-0.57940780	0.228365484	0.9319896
Leaves and fruits-Bark	0.41250567	-1.55519035	2.380201681	0.9996671
Roots-Bark	-0.24313090	-1.65511612	1.168854323	0.9999355
Stems-Bark	-0.20864389	-0.63464398	0.217356201	0.8671013
Whole plant-Bark	-0.05163817	-0.88438162	0.781105288	1.0000000
Wood-Bark	-0.09832137	-0.69658192	0.499939193	0.9999566

Inflorescence-Fruits	0.16217507	-1.30289454	1.627244673	0.9999986
Leaves-Fruits	-1.03842786	-2.09708831	0.020232593	0.0596834
Leaves and fruits-Fruits	-0.45040103	-2.64800544	1.747203375	0.9997236
Roots-Fruits	-1.10603760	-2.82398399	0.611908790	0.5651381
Stems-Fruits	-1.07155059	-2.13884324	-0.004257937	0.0481570
Whole plant-Fruits	-0.91454487	-2.19949591	0.370406179	0.4146034
Wood-Fruits	-0.96122807	-2.10820375	0.185747621	0.1911146
Leaves-Inflorescence	-1.20060293	-2.25926338	-0.141942476	0.0126912
Leaves and fruits-Inflorescence	-0.61257610	-2.81018051	1.585028307	0.9967995
Roots-Inflorescence	-1.26821267	-2.98615906	0.449733722	0.3599797
Stems-Inflorescence	-1.23372566	-2.30101831	-0.166433005	0.0099442
Whole plant-Inflorescence	-1.07671993	-2.36167098	0.208231111	0.1912617
Wood-Inflorescence	-1.12340313	-2.27037882	0.023572553	0.0604733
Leaves and fruits-Leaves	0.58802683	-1.36230600	2.538359653	0.9942238
Roots-Leaves	-0.06760974	-1.45529588	1.320076391	1.0000000
Stems-Leaves	-0.03312273	-0.36994110	0.303695633	0.9999995
Whole plant-Leaves	0.12388299	-0.66695972	0.914725703	0.9999712
Wood-Leaves	0.07719979	-0.46121104	0.615610629	0.9999865
Roots-Leaves and fruits	-0.65563657	-3.02932062	1.718047485	0.9970155
Stems-Leaves and fruits	-0.62114956	-2.57618147	1.333882358	0.9915177
Whole plant-Leaves and fruits	-0.46414383	-2.54600247	1.617714801	0.9994500
Wood-Leaves and fruits	-0.51082703	-2.51047435	1.488820288	0.9983706
Stems-Roots	0.03448701	-1.35979577	1.428769788	1.0000000
Whole plant-Roots	0.19149273	-1.37567351	1.758658981	0.9999966
Wood-Roots	0.14480954	-1.31137180	1.600990871	0.9999994
Whole plant-Stems	0.15700572	-0.64535570	0.959367146	0.9998116
Wood-Stems	0.11032252	-0.44486923	0.665514281	0.9997859
Wood-Whole plant	-0.04668320	-0.95234509	0.858978696	1.0000000

Families

Malpighiaceae-Lauraceae	-1,978693751	-3,51302532	-0,444362181	0,0005192
Lauraceae-Euphorbiaceae	1,800228841	0,350421784	3,250035899	0,0012218
Lauraceae-Fabaceae	1,697098501	0,301104545	3,093092457	0,0019153
Lauraceae-Annonaceae	1,704489447	0,222420681	3,186558213	0,0056639
Lauraceae-Dilleniaceae	2,411053704	0,260642323	4,561465085	0,0089106
Meliaceae-Lauraceae	-1,889082147	-3,644885687	-0,133278606	0,0175804
Sapotaceae-Lauraceae	-1,929862138	-3,729025382	-0,130698895	0,0184339
Sapindaceae-Lauraceae	-1,609596436	-3,118424873	-0,100767998	0,0200608
Malvaceae-Lauraceae	-2,04962174	-3,973008151	-0,126235329	0,020396
Siparunaceae-Lauraceae	-1,909791167	-3,708954411	-0,110627924	0,021642
Lauraceae-Costaceae	1,700601821	0,091381295	3,309822347	0,0231388
Loranthaceae-Lauraceae	-1,949016743	-3,802438265	-0,095595221	0,0249045
Solanaceae-Lauraceae	-1,543442125	-3,064012595	-0,022871655	0,0410494
Lauraceae-Bignoniaceae	1,820373311	0,021210068	3,619536554	0,0428566
Lauraceae-Apocynaceae	1,662054623	-0,003646871	3,327756116	0,0514344
Rubiaceae-Lauraceae	-1,794476669	-3,593639912	0,004686575	0,0517106
Vochysiaceae-Lauraceae	-2,130124826	-4,280536208	0,020286555	0,0564364
Orobanchaceae-Lauraceae	-2,07826572	-4,228677101	0,072145661	0,0761888
Lauraceae-Combretaceae	2,01783601	-0,132575371	4,168247391	0,1061758
Salicaceae-Lauraceae	-1,40160285	-2,935934419	0,132728719	0,1400313
Myrtaceae-Lauraceae	-1,844606449	-3,995017831	0,305804932	0,2449298
Lauraceae-Celastraceae	1,412817163	-0,252884331	3,078518656	0,2673108
Lauraceae-Clusiaceae	1,803548277	-0,346863104	3,953959659	0,2906057
Dilleniaceae-Asteraceae	-2,025994766	-4,570395826	0,518406293	0,4082505
Malpighiaceae-Asteraceae	-1,593634813	-3,643971616	0,456701991	0,4665869
Moraceae-Lauraceae	-2,092312224	-4,812391372	0,627766925	0,4919833
Polygalaceae-Lauraceae	-2,013081002	-4,733160151	0,706998146	0,5855017
Lauraceae-Chrysobalanaceae	1,176310514	-0,449247696	2,801868722	0,6379844

Euphorbiaceae-Asteraceae	-1,415169904	-3,403045188	0,572705381	0,6745907
Malvaceae-Asteraceae	-1,664562802	-4,020220445	0,691094841	0,6907166
Malpighiaceae-Chrysobalanaceae	-0,802383237	-1,941329051	0,336562577	0,6971459
Vochysiaceae-Asteraceae	-1,745065889	-4,289466948	0,799335171	0,7514566
Sapotaceae-Asteraceae	-1,5448032	-3,800173684	0,710567284	0,7539743
Piperaceae-Lauraceae	-1,225488299	-3,024651542	0,573674945	0,7644735
Loranthaceae-Asteraceae	-1,563957806	-3,862844271	0,73492866	0,7667464
Meliaceae-Asteraceae	-1,504023209	-3,724958534	0,716912116	0,7751465
Siparunaceae-Asteraceae	-1,524732229	-3,780102713	0,730638255	0,7782387
Fabaceae-Asteraceae	-1,312039563	-3,261015388	0,636936262	0,7857696
Lythraceae-Lauraceae	-1,813071799	-4,533150947	0,90700735	0,8028346
Orobanchaceae-Asteraceae	-1,693206782	-4,237607842	0,851194278	0,8055611
Asteraceae-Annonaceae	1,319430509	-0,692095148	3,330956167	0,8286167
Dilleniaceae-Chrysobalanaceae	-1,234743191	-3,123471152	0,653984771	0,8337017
Melastomataceae-Lauraceae	-1,758327569	-4,478406718	0,961751579	0,8500662
Lauraceae-Convolvulaceae	1,517159319	-0,838498324	3,872816962	0,855173
Combretaceae-Asteraceae	-1,632777072	-4,177178132	0,911623988	0,8600927
Bignoniaceae-Asteraceae	-1,435314373	-3,690684857	0,820056111	0,8709165
Lauraceae-Cyperaceae	1,70358334	-1,016495809	4,423662488	0,8900398
Rubiaceae-Asteraceae	-1,409417731	-3,664788215	0,845952753	0,8925103
Costaceae-Asteraceae	-1,315542883	-3,422507131	0,791421366	0,8934617
Humiriaceae-Dilleniaceae	1,32696921	-0,823442172	3,477380591	0,9058423
Euphorbiaceae-Chrysobalanaceae	-0,623918328	-1,646153481	0,398316825	0,9163799
Sapindaceae-Asteraceae	-1,224537498	-3,255859948	0,806784952	0,9271787
Asteraceae-Apocynaceae	1,276995685	-0,873415697	3,427407066	0,9387737
Malpighiaceae-Humiriaceae	-0,894609256	-2,428940825	0,639722313	0,9508666
Piperaceae-Dilleniaceae	1,185565406	-0,854493956	3,225624767	0,9528219
Salicaceae-Malpighiaceae	0,577090901	-0,427364893	1,581546694	0,9591225
Myrtaceae-Asteraceae	-1,459547512	-4,003948571	1,084853548	0,9599289

Solanaceae-Asteraceae	-1,158383187	-3,198442549	0,881676174	0,9648541
Lauraceae-Humiriaceae	1,084084495	-0,839301917	3,007470906	0,968106
Moraceae-Asteraceae	-1,707253286	-4,748394226	1,333887654	0,9697546
Clusiaceae-Asteraceae	-1,41848934	-3,962890399	1,12591172	0,9724534
Salicaceae-Dilleniaceae	1,009450854	-0,80135758	2,820259289	0,9724773
Fabaceae-Chrysobalanaceae	-0,520787987	-1,465151968	0,423575993	0,9762597
Piperaceae-Malpighiaceae	0,753205452	-0,622202289	2,128613193	0,9784656
Malvaceae-Chrysobalanaceae	-0,873311227	-2,498869436	0,752246982	0,9836223
Polygalaceae-Asteraceae	-1,628022064	-4,669163005	1,413118876	0,9844506
Dilleniaceae-Celastraceae	-0,998236541	-2,921622953	0,92514987	0,9902553
Sapotaceae-Chrysobalanaceae	-0,753551625	-2,230038191	0,722934941	0,9925146
Vochysiaceae-Chrysobalanaceae	-0,953814313	-2,842542274	0,934913649	0,9936852
Malvaceae-Humiriaceae	-0,965537246	-2,888923657	0,957849166	0,9942711
Loranthaceae-Chrysobalanaceae	-0,77270623	-2,314846153	0,769433693	0,9944442
Meliaceae-Chrysobalanaceae	-0,712771633	-2,136102332	0,710559065	0,9944957
Siparunaceae-Chrysobalanaceae	-0,733480654	-2,20996722	0,743005912	0,9951809
Salicaceae-Asteraceae	-1,016543912	-3,066880716	1,033792892	0,9953372
Chrysobalanaceae-Annonaceae	0,528178934	-0,53931909	1,595676957	0,995494
Humiriaceae-Euphorbiaceae	0,716144347	-0,733662711	2,165951404	0,9956184
Vochysiaceae-Humiriaceae	-1,046040332	-3,196451713	1,104371049	0,9966252
Solanaceae-Dilleniaceae	0,867611579	-0,931551665	2,666774822	0,9970968
Celastraceae-Asteraceae	-1,027758225	-3,178169606	1,122653157	0,9975187
Orobanchaceae-Chrysobalanaceae	-0,901955207	-2,790683168	0,986772755	0,9975542
Malpighiaceae-Celastraceae	-0,565876588	-1,761418115	0,629664939	0,997912
Sapotaceae-Humiriaceae	-0,845777644	-2,644940887	0,9533856	0,998154
Lythraceae-Asteraceae	-1,428012861	-4,469153801	1,613128079	0,9981913
Loranthaceae-Humiriaceae	-0,864932249	-2,718353771	0,988489273	0,9983839
Orobanchaceae-Humiriaceae	-0,994181226	-3,144592607	1,156230156	0,9986393
Siparunaceae-Humiriaceae	-0,825706673	-2,624869916	0,973456571	0,998813

Meliaceae-Humiriaceae	-0,804997652	-2,560801193	0,950805888	0,9988351
Salicaceae-Euphorbiaceae	0,398625991	-0,471258243	1,268510226	0,9988458
Piperaceae-Malvaceae	0,824133442	-0,975029802	2,623296685	0,9988546
Simaroubaceae-Lauraceae	-1,637337537	-5,235664024	1,96098895	0,9989893
Melastomataceae-Asteraceae	-1,373268631	-4,414409571	1,667872309	0,9991258
Piperaceae-Euphorbiaceae	0,574740543	-0,705694381	1,855175466	0,9992207
Sapindaceae-Dilleniaceae	0,801457268	-0,987793155	2,590707691	0,9992514
Combretaceae-Chrysobalanaceae	-0,841525496	-2,730253458	1,047202465	0,9993246
Lauraceae-Boraginaceae	1,210885275	-1,509193874	3,930964423	0,9993358
Vochysiaceae-Piperaceae	-0,904636528	-2,944695889	1,135422834	0,9993843
Solanaceae-Malpighiaceae	0,435251625	-0,548055362	1,418558613	0,9994055
Humiriaceae-Fabaceae	0,613014006	-0,782979949	2,009007962	0,9994918
Chrysobalanaceae-Bignoniaceae	0,644062798	-0,832423769	2,120549364	0,9995546
Humiriaceae-Combretaceae	0,933751515	-1,216659866	3,084162897	0,9995935
Cyperaceae-Asteraceae	-1,318524402	-4,359665342	1,722616538	0,9996056
Costaceae-Chrysobalanaceae	-0,524291307	-1,762279556	0,713696942	0,9997552
Sapotaceae-Piperaceae	-0,70437384	-2,370075333	0,961327654	0,9997627
Salicaceae-Malvaceae	0,64801889	-0,886312679	2,18235046	0,9997687
Fabaceae-Dilleniaceae	0,713955203	-0,981230022	2,409140428	0,9997817
Piperaceae-Loranthaceae	0,723528445	-1,000636404	2,447693294	0,9997975
Rubiaceae-Chrysobalanaceae	-0,618166155	-2,094652721	0,858320411	0,999807
Humiriaceae-Annonaceae	0,620404953	-0,861663813	2,102473719	0,9998076
Piperaceae-Orobanchaceae	0,852777422	-1,18728194	2,892836783	0,9998132
Convolvulaceae-Asteraceae	-1,132100381	-3,85217953	1,587978767	0,9998295
Dilleniaceae-Boraginaceae	-1,20016843	-4,085248046	1,684911188	0,9998313
Siparunaceae-Piperaceae	-0,684302869	-2,350004362	0,981398625	0,9998705
Piperaceae-Meliaceae	0,663593848	-0,955177032	2,282364728	0,9998763
Humiriaceae-Bignoniaceae	0,736288817	-1,062874427	2,53545206	0,9998807
Vochysiaceae-Salicaceae	-0,728521977	-2,539330411	1,082286458	0,9999174

Dilleniaceae-Annonaceae	-0,706564257	-2,473307489	1,060178975	0,9999274
Rubiaceae-Humiriaceae	-0,710392174	-2,509555418	1,088771069	0,9999452
Sapindaceae-Chrysobalanaceae	-0,433285922	-1,537635259	0,671063414	0,9999524
Dilleniaceae-Apocynaceae	-0,748999082	-2,672385493	1,17438733	0,9999597
Piperaceae-Combretaceae	0,792347711	-1,24771165	2,832407073	0,999962
Piperaceae-Fabaceae	0,471610202	-0,747558454	1,690778859	0,9999653
Sapotaceae-Salicaceae	-0,528259288	-1,903667029	0,847148453	0,9999705
Humiriaceae-Costaceae	0,616517326	-0,9927032	2,225737852	0,9999721
Sapindaceae-Malpighiaceae	0,369097315	-0,595952597	1,334147226	0,9999732
Malvaceae-Celastraceae	-0,636804578	-2,302506071	1,028896916	0,9999735
Salicaceae-Fabaceae	0,295495651	-0,481393789	1,072385091	0,9999764
Dilleniaceae-Costaceae	-0,710451883	-2,585137063	1,164233296	0,9999783
Salicaceae-Loranthaceae	0,547413894	-0,898244924	1,993072711	0,9999787
Salicaceae-Orobanchaceae	0,67666287	-1,134145564	2,487471305	0,9999843
Chrysobalanaceae-Asteraceae	-0,791251576	-2,910720173	1,328217022	0,9999846
Vochysiaceae-Celastraceae	-0,717307664	-2,640694075	1,206078748	0,999985
Piperaceae-Asteraceae	-0,840429361	-3,095799845	1,414941123	0,9999853
Chrysobalanaceae-Apocynaceae	0,485744109	-0,824822818	1,796311036	0,999987
Moraceae-Humiriaceae	-1,008227729	-3,728306878	1,711851419	0,999987
Salicaceae-Meliaceae	0,487479297	-0,830702841	1,805661435	0,9999877
Siparunaceae-Salicaceae	-0,508188317	-1,883596058	0,867219424	0,9999879
Piperaceae-Annonaceae	0,479001149	-0,837851507	1,795853804	0,9999917
Moraceae-Chrysobalanaceae	-0,91600171	-3,434305659	1,602302239	0,9999917
Malpighiaceae-Fabaceae	-0,28159525	-1,05848469	0,49529419	0,9999923
Piperaceae-Bignoniaceae	0,594885012	-1,070816481	2,260586506	0,9999946
Euphorbiaceae-Celastraceae	-0,387411679	-1,472347936	0,697524579	0,9999946
Myrtaceae-Chrysobalanaceae	-0,668295936	-2,557023898	1,220432026	0,9999957
Myrtaceae-Humiriaceae	-0,760521955	-2,910933336	1,389889426	0,9999958
Dilleniaceae-Convolvulaceae	-0,893894385	-3,438295445	1,650506675	0,9999964

Euphorbiaceae-Dilleniaceae	0,610824863	-1,128943606	2,350593332	0,9999964
Sapindaceae-Humiriaceae	-0,525511941	-2,034340379	0,983316496	0,9999971
Humiriaceae-Apocynaceae	0,577970128	-1,087731365	2,243671622	0,9999973
Orobanchaceae-Celastraceae	-0,665448557	-2,588834969	1,257937854	0,9999975
Polygalaceae-Humiriaceae	-0,928996508	-3,649075656	1,791082641	0,9999982
Rubiaceae-Piperaceae	-0,56898837	-2,234689864	1,096713123	0,9999982
Sapotaceae-Celastraceae	-0,517044975	-2,037615446	1,003525495	0,9999984
Salicaceae-Combretaceae	0,61623316	-1,194575275	2,427041594	0,9999984
Loranthaceae-Celastraceae	-0,536199581	-2,120597737	1,048198575	0,9999986
Humiriaceae-Clusiaceae	0,719463783	-1,430947598	2,869875164	0,9999989
Clusiaceae-Chrysobalanaceae	-0,627237764	-2,515965726	1,261490198	0,9999991
Polygalaceae-Chrysobalanaceae	-0,836770489	-3,355074437	1,68153346	0,9999991
Solanaceae-Malvaceae	0,506179615	-1,014390855	2,026750085	0,9999991
Salicaceae-Annonaceae	0,302886597	-0,619764964	1,225538159	0,9999993
Piperaceae-Moraceae	0,866823925	-1,766881386	3,500529236	0,9999993
Siparunaceae-Celastraceae	-0,496974004	-2,017544475	1,023596466	0,9999994
Solanaceae-Chrysobalanaceae	-0,367131612	-1,487470292	0,753207068	0,9999994
Vochysiaceae-Solanaceae	-0,586682701	-2,385845944	1,212480542	0,9999994
Simaroubaceae-Asteraceae	-1,252278599	-5,099051422	2,594494224	0,9999995
Meliaceae-Celastraceae	-0,476264984	-1,945275621	0,992745653	0,9999995
Piperaceae-Costaceae	0,475113522	-0,983366437	1,933593481	0,9999995
Vochysiaceae-Boraginaceae	-0,919239552	-3,804319169	1,965840065	0,9999997
Malpighiaceae-Boraginaceae	-0,767808476	-3,22821264	1,692595689	0,9999998
Combretaceae-Celastraceae	-0,605018847	-2,528405259	1,318367564	0,9999998
Salicaceae-Bignoniaceae	0,418770461	-0,95663728	1,794178202	0,9999999
Malvaceae-Boraginaceae	-0,838736466	-3,558815614	1,881342683	0,9999999
Orobanchaceae-Boraginaceae	-0,867380445	-3,752460062	2,017699172	0,9999999
Rubiaceae-Dilleniaceae	0,616577035	-1,423482326	2,656636397	0,9999999
Solanaceae-Euphorbiaceae	0,256786716	-0,588588805	1,102162237	0,9999999

Solanaceae-Humiriaceae	-0,459357631	-1,979928101	1,061212839	0,9999999
Piperaceae-Myrtaceae	0,619118151	-1,42094121	2,659177512	0,9999999
Polygalaceae-Piperaceae	-0,787592704	-3,421298014	1,846112607	0,9999999
Apocynaceae-Annonaceae	0,042434825	-1,085250417	1,170120067	1
Bignoniaceae-Annonaceae	-0,115883864	-1,432736519	1,200968792	1
Boraginaceae-Annonaceae	0,493604173	-1,934552147	2,921760493	1
Celastraceae-Annonaceae	0,291672285	-0,836012957	1,419357527	1
Clusiaceae-Annonaceae	-0,09905883	-1,865802062	1,667684402	1
Combretaceae-Annonaceae	-0,313346563	-2,080089795	1,45339667	1
Convolvulaceae-Annonaceae	0,187330128	-1,824195529	2,198855786	1
Costaceae-Annonaceae	0,003887626	-1,038562967	1,04633822	1
Cyperaceae-Annonaceae	0,000906108	-2,427250212	2,429062428	1
Euphorbiaceae-Annonaceae	-0,095739394	-0,869724564	0,678245776	1
Fabaceae-Annonaceae	0,007390946	-0,660375228	0,675157121	1
Loranthaceae-Annonaceae	-0,244527296	-1,634593438	1,145538845	1
Lythraceae-Annonaceae	-0,108582351	-2,536738671	2,319573969	1
Malpighiaceae-Annonaceae	-0,274204303	-1,196855865	0,648447258	1
Malvaceae-Annonaceae	-0,345132293	-1,827201059	1,136936473	1
Melastomataceae-Annonaceae	-0,053838122	-2,481994442	2,374318198	1
Meliaceae-Annonaceae	-0,1845927	-1,441556745	1,072371346	1
Moraceae-Annonaceae	-0,387822776	-2,815979096	2,040333544	1
Myrtaceae-Annonaceae	-0,140117002	-1,906860234	1,62662623	1
Orobanchaceae-Annonaceae	-0,373776273	-2,140519505	1,392966959	1
Polygalaceae-Annonaceae	-0,308591555	-2,736747875	2,119564765	1
Rubiaceae-Annonaceae	-0,089987222	-1,406839877	1,226865434	1
Sapindaceae-Annonaceae	0,094893011	-0,784695411	0,974481434	1
Sapotaceae-Annonaceae	-0,225372691	-1,542225346	1,091479964	1
Simaroubaceae-Annonaceae	0,067151911	-3,315903816	3,450207636	1
Siparunaceae-Annonaceae	-0,20530172	-1,522154375	1,111550935	1

Solanaceae-Annonaceae	0,161047322	-0,7385343	1,060628944	1
Vochysiaceae-Annonaceae	-0,425635379	-2,192378611	1,341107853	1
Bignoniaceae-Apocynaceae	-0,158318689	-1,678889159	1,362251782	1
Boraginaceae-Apocynaceae	0,451169348	-2,093231712	2,995570408	1
Celastraceae-Apocynaceae	0,24923746	-1,110802115	1,609277034	1
Clusiaceae-Apocynaceae	-0,141493655	-2,064880066	1,781892756	1
Combretaceae-Apocynaceae	-0,355781387	-2,279167799	1,567605024	1
Convolvulaceae-Apocynaceae	0,144895303	-2,005516078	2,295306685	1
Costaceae-Apocynaceae	-0,038547198	-1,328794027	1,251699631	1
Cyperaceae-Apocynaceae	-0,041528717	-2,585929777	2,502872343	1
Euphorbiaceae-Apocynaceae	-0,138174219	-1,223110476	0,946762038	1
Fabaceae-Apocynaceae	-0,035043878	-1,046945703	0,976857946	1
Loranthaceae-Apocynaceae	-0,286962121	-1,871360277	1,297436035	1
Lythraceae-Apocynaceae	-0,151017176	-2,695418236	2,393383884	1
Malpighiaceae-Apocynaceae	-0,316639128	-1,512180655	0,878902399	1
Malvaceae-Apocynaceae	-0,387567118	-2,053268611	1,278134376	1
Melastomataceae-Apocynaceae	-0,096272947	-2,640674006	2,448128113	1
Meliaceae-Apocynaceae	-0,227027524	-1,696038161	1,241983112	1
Moraceae-Apocynaceae	-0,430257601	-2,974658661	2,114143459	1
Myrtaceae-Apocynaceae	-0,182551827	-2,105938238	1,740834584	1
Orobanchaceae-Apocynaceae	-0,416211098	-2,339597509	1,507175314	1
Piperaceae-Apocynaceae	0,436566324	-1,084004146	1,957136794	1
Polygalaceae-Apocynaceae	-0,35102638	-2,895427439	2,19337468	1
Rubiaceae-Apocynaceae	-0,132422046	-1,652992516	1,388148424	1
Salicaceae-Apocynaceae	0,260451773	-0,935089754	1,4559933	1
Sapindaceae-Apocynaceae	0,052458187	-1,110172207	1,21508858	1
Sapotaceae-Apocynaceae	-0,267807516	-1,788377986	1,252762954	1
Simaroubaceae-Apocynaceae	0,024717086	-3,442717079	3,49215125	1
Siparunaceae-Apocynaceae	-0,247736545	-1,768307015	1,272833925	1

Solanaceae-Apocynaceae	0,118612497	-1,059216324	1,296441319	1
Vochysiaceae-Apocynaceae	-0,468070204	-2,391456615	1,455316207	1
Boraginaceae-Asteraceae	-0,825826337	-3,866967277	2,215314603	1
Humiriaceae-Asteraceae	-0,699025557	-3,0546832	1,656632086	1
Lauraceae-Asteraceae	0,385058938	-1,970598705	2,740716581	1
Boraginaceae-Bignoniaceae	0,609488036	-2,024217274	3,243193347	1
Celastraceae-Bignoniaceae	0,407556148	-1,113014322	1,928126618	1
Clusiaceae-Bignoniaceae	0,016825034	-2,023234328	2,056884395	1
Combretaceae-Bignoniaceae	-0,197462699	-2,23752206	1,842596662	1
Convolvulaceae-Bignoniaceae	0,303213992	-1,952156492	2,558584476	1
Costaceae-Bignoniaceae	0,11977149	-1,338708469	1,578251449	1
Cyperaceae-Bignoniaceae	0,116789971	-2,516915339	2,750495282	1
Dilleniaceae-Bignoniaceae	-0,590680393	-2,630739755	1,449378968	1
Euphorbiaceae-Bignoniaceae	0,02014447	-1,260290454	1,300579393	1
Fabaceae-Bignoniaceae	0,12327481	-1,095893847	1,342443467	1
Loranthaceae-Bignoniaceae	-0,128643432	-1,852808282	1,595521417	1
Lythraceae-Bignoniaceae	0,007301512	-2,626403798	2,641006823	1
Malpighiaceae-Bignoniaceae	-0,15832044	-1,53372818	1,217087301	1
Malvaceae-Bignoniaceae	-0,229248429	-2,028411673	1,569914814	1
Melastomataceae-Bignoniaceae	0,062045742	-2,571659569	2,695751053	1
Meliaceae-Bignoniaceae	-0,068708836	-1,687479716	1,550062044	1
Moraceae-Bignoniaceae	-0,271938913	-2,905644223	2,361766398	1
Myrtaceae-Bignoniaceae	-0,024233139	-2,0642925	2,015826223	1
Orobanchaceae-Bignoniaceae	-0,257892409	-2,29795177	1,782166952	1
Polygalaceae-Bignoniaceae	-0,192707691	-2,826413002	2,440997619	1
Rubiaceae-Bignoniaceae	0,025896642	-1,639804851	1,691598136	1
Sapindaceae-Bignoniaceae	0,210776875	-1,136121912	1,557675662	1
Sapotaceae-Bignoniaceae	-0,109488827	-1,775190321	1,556212666	1
Simaroubaceae-Bignoniaceae	0,183035774	-3,35045069	3,716522239	1

Siparunaceae-Bignoniaceae	-0,089417856	-1,75511935	1,576283637	1
Solanaceae-Bignoniaceae	0,276931186	-1,083108389	1,63697076	1
Vochysiaceae-Bignoniaceae	-0,309751515	-2,349810877	1,730307846	1
Celastraceae-Boraginaceae	-0,201931888	-2,746332948	2,342469172	1
Chrysobalanaceae-Boraginaceae	0,034574761	-2,483729188	2,55287871	1
Clusiaceae-Boraginaceae	-0,592663003	-3,47774262	2,292416614	1
Combretaceae-Boraginaceae	-0,806950735	-3,692030352	2,078128882	1
Convolvulaceae-Boraginaceae	-0,306274045	-3,347414985	2,734866896	1
Costaceae-Boraginaceae	-0,489716546	-2,99750561	2,018072518	1
Cyperaceae-Boraginaceae	-0,492698065	-3,824101052	2,838704922	1
Euphorbiaceae-Boraginaceae	-0,589343567	-2,997943947	1,819256813	1
Fabaceae-Boraginaceae	-0,486213226	-2,86281046	1,890384008	1
Humiriaceae-Boraginaceae	0,12680078	-2,593278368	2,846879929	1
Loranthaceae-Boraginaceae	-0,738131469	-3,409196168	1,93293323	1
Lythraceae-Boraginaceae	-0,602186524	-3,933589511	2,729216463	1
Melastomataceae-Boraginaceae	-0,547442295	-3,878845282	2,783960693	1
Meliaceae-Boraginaceae	-0,678196872	-3,282474384	1,92608064	1
Moraceae-Boraginaceae	-0,881426949	-4,212829936	2,449976038	1
Myrtaceae-Boraginaceae	-0,633721175	-3,518800792	2,251358442	1
Piperaceae-Boraginaceae	-0,014603024	-2,648308335	2,619102287	1
Polygalaceae-Boraginaceae	-0,802195728	-4,133598715	2,529207259	1
Rubiaceae-Boraginaceae	-0,583591394	-3,217296705	2,050113917	1
Salicaceae-Boraginaceae	-0,190717575	-2,65112174	2,269686589	1
Sapindaceae-Boraginaceae	-0,398711161	-2,843292627	2,045870304	1
Sapotaceae-Boraginaceae	-0,718976864	-3,352682174	1,914728447	1
Simaroubaceae-Boraginaceae	-0,426452262	-4,506570985	3,653666461	1
Siparunaceae-Boraginaceae	-0,698905893	-3,332611203	1,934799418	1
Solanaceae-Boraginaceae	-0,332556851	-2,784403062	2,11928936	1
Chrysobalanaceae-Celastraceae	0,236506649	-1,074060277	1,547073576	1

Clusiaceae-Celastraceae	-0,390731115	-2,314117526	1,532655297	1
Convolvulaceae-Celastraceae	-0,104342156	-2,254753538	2,046069225	1
Costaceae-Celastraceae	-0,287784658	-1,578031487	1,002462171	1
Cyperaceae-Celastraceae	-0,290766177	-2,835167237	2,253634883	1
Fabaceae-Celastraceae	-0,284281338	-1,296183163	0,727620486	1
Humiriaceae-Celastraceae	0,328732668	-1,336968825	1,994434162	1
Lythraceae-Celastraceae	-0,400254636	-2,944655696	2,144146424	1
Melastomataceae-Celastraceae	-0,345510406	-2,889911466	2,198890653	1
Moraceae-Celastraceae	-0,679495061	-3,223896121	1,864905999	1
Myrtaceae-Celastraceae	-0,431789287	-2,355175698	1,491597125	1
Piperaceae-Celastraceae	0,187328864	-1,333241606	1,707899334	1
Polygalaceae-Celastraceae	-0,60026384	-3,144664899	1,94413722	1
Rubiaceae-Celastraceae	-0,381659506	-1,902229976	1,138910964	1
Salicaceae-Celastraceae	0,011214313	-1,184327214	1,20675584	1
Sapindaceae-Celastraceae	-0,196779273	-1,359409667	0,96585112	1
Simaroubaceae-Celastraceae	-0,224520374	-3,691954538	3,24291379	1
Solanaceae-Celastraceae	-0,130624963	-1,308453784	1,047203859	1
Convolvulaceae-Chrysobalanaceae	-0,340848806	-2,460317403	1,778619792	1
Cyperaceae-Chrysobalanaceae	-0,527272826	-3,045576775	1,991031123	1
Humiriaceae-Chrysobalanaceae	0,092226019	-1,53333219	1,717784228	1
Lythraceae-Chrysobalanaceae	-0,636761285	-3,155065234	1,881542664	1
Melastomataceae-Chrysobalanaceae	-0,582017056	-3,100321004	1,936286893	1
Piperaceae-Chrysobalanaceae	-0,049177785	-1,525664351	1,427308781	1
Salicaceae-Chrysobalanaceae	-0,225292336	-1,364238151	0,913653478	1
Simaroubaceae-Chrysobalanaceae	-0,461027023	-3,909356722	2,987302675	1
Combretaceae-Clusiaceae	-0,214287732	-2,569945375	2,141369911	1
Convolvulaceae-Clusiaceae	0,286388958	-2,258012101	2,830790018	1
Costaceae-Clusiaceae	0,102946457	-1,771738723	1,977631636	1
Cyperaceae-Clusiaceae	0,099964938	-2,785114679	2,985044555	1

Dilleniaceae-Clusiaceae	-0,607505427	-2,96316307	1,748152216	1
Euphorbiaceae-Clusiaceae	0,003319436	-1,736449033	1,743087905	1
Fabaceae-Clusiaceae	0,106449777	-1,588735448	1,801635001	1
Loranthaceae-Clusiaceae	-0,145468466	-2,233535792	1,942598861	1
Lythraceae-Clusiaceae	-0,009523521	-2,894603138	2,875556096	1
Malpighiaceae-Clusiaceae	-0,175145473	-1,985953908	1,635662961	1
Malvaceae-Clusiaceae	-0,246073463	-2,396484844	1,904337919	1
Melastomataceae-Clusiaceae	0,045220708	-2,839858909	2,930300325	1
Meliaceae-Clusiaceae	-0,085533869	-2,087457918	1,916390179	1
Moraceae-Clusiaceae	-0,288763946	-3,173843563	2,596315671	1
Myrtaceae-Clusiaceae	-0,041058172	-2,396715815	2,314599471	1
Orobanchaceae-Clusiaceae	-0,274717443	-2,630375086	2,0809402	1
Piperaceae-Clusiaceae	0,578059979	-1,461999382	2,61811934	1
Polygalaceae-Clusiaceae	-0,209532725	-3,094612342	2,675546892	1
Rubiaceae-Clusiaceae	0,009071609	-2,030987753	2,04913097	1
Salicaceae-Clusiaceae	0,401945428	-1,408863007	2,212753862	1
Sapindaceae-Clusiaceae	0,193951842	-1,595298581	1,983202264	1
Sapotaceae-Clusiaceae	-0,126313861	-2,166373222	1,913745501	1
Simaroubaceae-Clusiaceae	0,166210741	-3,558411029	3,89083251	1
Siparunaceae-Clusiaceae	-0,10624289	-2,146302251	1,933816472	1
Solanaceae-Clusiaceae	0,260106152	-1,539057091	2,059269396	1
Vochysiaceae-Clusiaceae	-0,326576549	-2,682234192	2,029081094	1
Convolvulaceae-Combretaceae	0,500676691	-2,043724369	3,045077751	1
Costaceae-Combretaceae	0,317234189	-1,557450991	2,191919369	1
Cyperaceae-Combretaceae	0,31425267	-2,570826947	3,199332287	1
Dilleniaceae-Combretaceae	-0,393217694	-2,748875337	1,962439949	1
Euphorbiaceae-Combretaceae	0,217607169	-1,5221613	1,957375638	1
Fabaceae-Combretaceae	0,320737509	-1,374447716	2,015922734	1
Loranthaceae-Combretaceae	0,068819267	-2,01924806	2,156886593	1

Lythraceae-Combretaceae	0,204764211	-2,680315406	3,089843828	1
Malpighiaceae-Combretaceae	0,039142259	-1,771666175	1,849950694	1
Malvaceae-Combretaceae	-0,03178573	-2,182197112	2,118625651	1
Melastomataceae-Combretaceae	0,259508441	-2,625571176	3,144588058	1
Meliaceae-Combretaceae	0,128753863	-1,873170185	2,130677911	1
Moraceae-Combretaceae	-0,074476214	-2,959555831	2,810603403	1
Myrtaceae-Combretaceae	0,17322956	-2,182428083	2,528887203	1
Orobanchaceae-Combretaceae	-0,06042971	-2,416087353	2,295227933	1
Polygalaceae-Combretaceae	0,004755008	-2,880324609	2,889834625	1
Rubiaceae-Combretaceae	0,223359341	-1,81670002	2,263418703	1
Sapindaceae-Combretaceae	0,408239574	-1,381010849	2,197489997	1
Sapotaceae-Combretaceae	0,087973872	-1,95208549	2,128033233	1
Simaroubaceae-Combretaceae	0,380498473	-3,344123297	4,105120243	1
Siparunaceae-Combretaceae	0,108044843	-1,932014519	2,148104204	1
Solanaceae-Combretaceae	0,474393885	-1,324769359	2,273557128	1
Vochysiaceae-Combretaceae	-0,112288817	-2,467946459	2,243368827	1
Costaceae-Convolvulaceae	-0,183442502	-2,29040675	1,923521747	1
Cyperaceae-Convolvulaceae	-0,186424021	-3,227564961	2,85471692	1
Euphorbiaceae-Convolvulaceae	-0,283069522	-2,270944807	1,704805763	1
Fabaceae-Convolvulaceae	-0,179939182	-2,128915007	1,769036644	1
Humiriaceae-Convolvulaceae	0,433074825	-1,922582818	2,788732468	1
Loranthaceae-Convolvulaceae	-0,431857424	-2,73074389	1,867029041	1
Lythraceae-Convolvulaceae	-0,29591248	-3,33705342	2,745228461	1
Malpighiaceae-Convolvulaceae	-0,461534431	-2,511871235	1,588802372	1
Malvaceae-Convolvulaceae	-0,532462421	-2,888120064	1,823195222	1
Melastomataceae-Convolvulaceae	-0,24116825	-3,28230919	2,79997269	1
Meliaceae-Convolvulaceae	-0,371922828	-2,592858152	1,849012497	1
Moraceae-Convolvulaceae	-0,575152905	-3,616293845	2,465988036	1
Myrtaceae-Convolvulaceae	-0,32744713	-2,87184819	2,216953929	1

Orobanchaceae-Convolvulaceae	-0,561106401	-3,105507461	1,983294659	1
Piperaceae-Convolvulaceae	0,291671021	-1,963699463	2,547041505	1
Polygalaceae-Convolvulaceae	-0,495921683	-3,537062623	2,545219257	1
Rubiaceae-Convolvulaceae	-0,27731735	-2,532687834	1,978053134	1
Salicaceae-Convolvulaceae	0,115556469	-1,934780334	2,165893273	1
Sapindaceae-Convolvulaceae	-0,092437117	-2,123759567	1,938885334	1
Sapotaceae-Convolvulaceae	-0,412702819	-2,668073303	1,842667665	1
Simaroubaceae-Convolvulaceae	-0,120178218	-3,96695104	3,726594605	1
Siparunaceae-Convolvulaceae	-0,392631848	-2,648002332	1,862738636	1
Solanaceae-Convolvulaceae	-0,026282806	-2,066342168	2,013776555	1
Vochysiaceae-Convolvulaceae	-0,612965507	-3,157366567	1,931435552	1
Cyperaceae-Costaceae	-0,002981519	-2,510770583	2,504807545	1
Euphorbiaceae-Costaceae	-0,099627021	-1,095677179	0,896423138	1
Fabaceae-Costaceae	0,00350332	-0,912452213	0,919458853	1
Loranthaceae-Costaceae	-0,248414923	-1,773323691	1,276493846	1
Lythraceae-Costaceae	-0,112469978	-2,620259042	2,395319086	1
Malpighiaceae-Costaceae	-0,27809193	-1,393595752	0,837411893	1
Malvaceae-Costaceae	-0,349019919	-1,958240445	1,260200607	1
Melastomataceae-Costaceae	-0,057725748	-2,565514812	2,450063315	1
Meliaceae-Costaceae	-0,188480326	-1,593123159	1,216162506	1
Moraceae-Costaceae	-0,391710403	-2,899499467	2,116078661	1
Myrtaceae-Costaceae	-0,144004629	-2,018689808	1,730680551	1
Orobanchaceae-Costaceae	-0,377663899	-2,252349079	1,49702128	1
Polygalaceae-Costaceae	-0,312479181	-2,820268245	2,195309882	1
Rubiaceae-Costaceae	-0,093874848	-1,552354807	1,364605111	1
Salicaceae-Costaceae	0,298998971	-0,816504852	1,414502794	1
Sapindaceae-Costaceae	0,091005385	-0,989151394	1,171162164	1
Sapotaceae-Costaceae	-0,229260317	-1,687740276	1,229219641	1
Simaroubaceae-Costaceae	0,063264284	-3,377393926	3,503922494	1

Siparunaceae-Costaceae	-0,209189346	-1,667669305	1,249290612	1
Solanaceae-Costaceae	0,157159696	-0,939339264	1,253658655	1
Vochysiaceae-Costaceae	-0,429523006	-2,304208185	1,445162174	1
Dilleniaceae-Cyperaceae	-0,707470365	-3,592549981	2,177609253	1
Euphorbiaceae-Cyperaceae	-0,096645502	-2,505245882	2,311954878	1
Fabaceae-Cyperaceae	0,006484839	-2,370112395	2,383082073	1
Humiriaceae-Cyperaceae	0,619498845	-2,100580303	3,339577994	1
Loranthaceae-Cyperaceae	-0,245433404	-2,916498103	2,425631295	1
Lythraceae-Cyperaceae	-0,109488459	-3,440891446	3,221914528	1
Malpighiaceae-Cyperaceae	-0,275110411	-2,735514575	2,185293754	1
Malvaceae-Cyperaceae	-0,346038401	-3,066117549	2,374040748	1
Melastomataceae-Cyperaceae	-0,05474423	-3,386147217	3,276658758	1
Meliaceae-Cyperaceae	-0,185498807	-2,789776319	2,418778705	1
Moraceae-Cyperaceae	-0,388728884	-3,720131871	2,942674103	1
Myrtaceae-Cyperaceae	-0,14102311	-3,026102727	2,744056507	1
Orobanchaceae-Cyperaceae	-0,37468238	-3,259761997	2,510397237	1
Piperaceae-Cyperaceae	0,478095041	-2,15561027	3,111800352	1
Polygalaceae-Cyperaceae	-0,309497663	-3,64090065	3,021905324	1
Rubiaceae-Cyperaceae	-0,090893329	-2,72459864	2,542811982	1
Salicaceae-Cyperaceae	0,30198049	-2,158423675	2,762384654	1
Sapindaceae-Cyperaceae	0,093986904	-2,350594562	2,538568369	1
Sapotaceae-Cyperaceae	-0,226278799	-2,859984109	2,407426512	1
Simaroubaceae-Cyperaceae	0,066245803	-4,01387292	4,146364526	1
Siparunaceae-Cyperaceae	-0,206207828	-2,839913138	2,427497483	1
Solanaceae-Cyperaceae	0,160141214	-2,291704997	2,611987425	1
Vochysiaceae-Cyperaceae	-0,426541487	-3,311621104	2,45853813	1
Loranthaceae-Dilleniaceae	0,462036961	-1,626030366	2,550104287	1
Lythraceae-Dilleniaceae	0,597981906	-2,287097712	3,483061522	1
Malpighiaceae-Dilleniaceae	0,432359954	-1,378448481	2,243168388	1

Malvaceae-Dilleniaceae	0,361431964	-1,788979417	2,511843345	1
Melastomataceae-Dilleniaceae	0,652726135	-2,232353482	3,537805752	1
Meliaceae-Dilleniaceae	0,521971557	-1,479952491	2,523895605	1
Moraceae-Dilleniaceae	0,318741481	-2,566338136	3,203821097	1
Myrtaceae-Dilleniaceae	0,566447255	-1,789210388	2,922104898	1
Orobanchaceae-Dilleniaceae	0,332787984	-2,022869659	2,688445627	1
Polygalaceae-Dilleniaceae	0,397972702	-2,487106915	3,283052319	1
Sapotaceae-Dilleniaceae	0,481191566	-1,558867795	2,521250927	1
Simaroubaceae-Dilleniaceae	0,773716167	-2,950905602	4,498337937	1
Siparunaceae-Dilleniaceae	0,501262537	-1,538796824	2,541321898	1
Vochysiaceae-Dilleniaceae	0,280928878	-2,074728765	2,636586521	1
Fabaceae-Euphorbiaceae	0,103130341	-0,489595854	0,695856535	1
Loranthaceae-Euphorbiaceae	-0,148787902	-1,504404572	1,206828768	1
Lythraceae-Euphorbiaceae	-0,012842957	-2,421443337	2,395757423	1
Malpighiaceae-Euphorbiaceae	-0,178464909	-1,048349144	0,691419325	1
Malvaceae-Euphorbiaceae	-0,249392899	-1,699199956	1,200414159	1
Melastomataceae-Euphorbiaceae	0,041901272	-2,366699108	2,450501652	1
Meliaceae-Euphorbiaceae	-0,088853306	-1,307611399	1,129904788	1
Moraceae-Euphorbiaceae	-0,292083382	-2,700683762	2,116516998	1
Myrtaceae-Euphorbiaceae	-0,044377608	-1,784146077	1,695390861	1
Orobanchaceae-Euphorbiaceae	-0,278036879	-2,017805348	1,46173159	1
Polygalaceae-Euphorbiaceae	-0,212852161	-2,621452541	2,195748219	1
Rubiaceae-Euphorbiaceae	0,005752173	-1,274682751	1,286187096	1
Sapindaceae-Euphorbiaceae	0,190632406	-0,633435838	1,014700649	1
Sapotaceae-Euphorbiaceae	-0,129633297	-1,41006822	1,150801627	1
Simaroubaceae-Euphorbiaceae	0,162891305	-3,206155849	3,531938458	1
Siparunaceae-Euphorbiaceae	-0,109562326	-1,389997249	1,170872598	1
Vochysiaceae-Euphorbiaceae	-0,329895985	-2,069664454	1,409872484	1
Loranthaceae-Fabaceae	-0,251918243	-1,54982239	1,045985905	1

Lythraceae-Fabaceae	-0,115973298	-2,492570532	2,260623936	1
Malvaceae-Fabaceae	-0,352523239	-1,748517195	1,043470716	1
Melastomataceae-Fabaceae	-0,061229068	-2,437826302	2,315368166	1
Meliaceae-Fabaceae	-0,191983646	-1,346206289	0,962238997	1
Moraceae-Fabaceae	-0,395213723	-2,771810957	1,981383511	1
Myrtaceae-Fabaceae	-0,147507949	-1,842693173	1,547677276	1
Orobanchaceae-Fabaceae	-0,381167219	-2,076352444	1,314018006	1
Polygalaceae-Fabaceae	-0,315982501	-2,692579735	2,060614732	1
Rubiaceae-Fabaceae	-0,097378168	-1,316546825	1,121790489	1
Sapindaceae-Fabaceae	0,087502065	-0,637720033	0,812724163	1
Sapotaceae-Fabaceae	-0,232763637	-1,451932294	0,986405019	1
Simaroubaceae-Fabaceae	0,059760964	-3,286481308	3,406003236	1
Siparunaceae-Fabaceae	-0,212692666	-1,431861323	1,00647599	1
Solanaceae-Fabaceae	0,153656376	-0,595688933	0,903001684	1
Vochysiaceae-Fabaceae	-0,433026326	-2,12821155	1,262158899	1
Lythraceae-Humiriaceae	-0,728987304	-3,449066453	1,991091844	1
Melastomataceae-Humiriaceae	-0,674243075	-3,394322223	2,045836074	1
Piperaceae-Humiriaceae	-0,141403804	-1,940567047	1,657759439	1
Salicaceae-Humiriaceae	-0,317518356	-1,851849925	1,216813214	1
Simaroubaceae-Humiriaceae	-0,553253042	-4,151579529	3,045073444	1
Lythraceae-Loranthaceae	0,135944945	-2,535119754	2,807009644	1
Malpighiaceae-Loranthaceae	-0,029677007	-1,475335824	1,41598181	1
Malvaceae-Loranthaceae	-0,100604997	-1,954026519	1,752816525	1
Melastomataceae-Loranthaceae	0,190689174	-2,480375525	2,861753873	1
Meliaceae-Loranthaceae	0,059934597	-1,618934703	1,738803896	1
Moraceae-Loranthaceae	-0,14329548	-2,814360179	2,527769219	1
Myrtaceae-Loranthaceae	0,104410294	-1,983657033	2,19247762	1
Orobanchaceae-Loranthaceae	-0,129248977	-2,217316303	1,95881835	1
Polygalaceae-Loranthaceae	-0,064064259	-2,735128958	2,60700044	1

Rubiaceae-Loranthaceae	0,154540075	-1,569624775	1,878704924	1
Sapindaceae-Loranthaceae	0,339420308	-1,0791421	1,757982715	1
Sapotaceae-Loranthaceae	0,019154605	-1,705010244	1,743319454	1
Simaroubaceae-Loranthaceae	0,311679207	-3,249740392	3,873098805	1
Siparunaceae-Loranthaceae	0,039225576	-1,684939273	1,763390425	1
Solanaceae-Loranthaceae	0,405574618	-1,025470666	1,836619902	1
Vochysiaceae-Loranthaceae	-0,181108083	-2,269175409	1,906959244	1
Malpighiaceae-Lythraceae	-0,165621952	-2,626026116	2,294782213	1
Malvaceae-Lythraceae	-0,236549942	-2,95662909	2,483529207	1
Melastomataceae-Lythraceae	0,05474423	-3,276658758	3,386147217	1
Meliaceae-Lythraceae	-0,076010348	-2,68028786	2,528267164	1
Moraceae-Lythraceae	-0,279240425	-3,610643412	3,052162562	1
Myrtaceae-Lythraceae	-0,031534651	-2,916614268	2,853544966	1
Orobanchaceae-Lythraceae	-0,265193921	-3,150273538	2,619885696	1
Piperaceae-Lythraceae	0,5875835	-2,046121811	3,221288811	1
Polygalaceae-Lythraceae	-0,200009204	-3,531412191	3,131393783	1
Rubiaceae-Lythraceae	0,01859513	-2,615110181	2,652300441	1
Salicaceae-Lythraceae	0,411468949	-2,048935216	2,871873113	1
Sapindaceae-Lythraceae	0,203475363	-2,241106103	2,648056828	1
Sapotaceae-Lythraceae	-0,11679034	-2,75049565	2,516914971	1
Simaroubaceae-Lythraceae	0,175734262	-3,904384461	4,255852985	1
Siparunaceae-Lythraceae	-0,096719369	-2,730424679	2,536985942	1
Solanaceae-Lythraceae	0,269629673	-2,182216538	2,721475884	1
Vochysiaceae-Lythraceae	-0,317053028	-3,202132645	2,568026589	1
Malvaceae-Malpighiaceae	-0,07092799	-1,605259559	1,46340358	1
Melastomataceae-Malpighiaceae	0,220366181	-2,240037983	2,680770346	1
Meliaceae-Malpighiaceae	0,089611604	-1,228570535	1,407793742	1
Moraceae-Malpighiaceae	-0,113618473	-2,574022637	2,346785691	1
Myrtaceae-Malpighiaceae	0,134087301	-1,676721133	1,944895736	1

Orobanchaceae-Malpighiaceae	-0,09957197	-1,910380404	1,711236465	1
Polygalaceae-Malpighiaceae	-0,034387252	-2,494791416	2,426016913	1
Rubiaceae-Malpighiaceae	0,184217082	-1,191190659	1,559624823	1
Sapotaceae-Malpighiaceae	0,048831612	-1,326576129	1,424239353	1
Simaroubaceae-Malpighiaceae	0,341356214	-3,06491911	3,747631538	1
Siparunaceae-Malpighiaceae	0,068902583	-1,306505158	1,444310324	1
Vochysiaceae-Malpighiaceae	-0,151431076	-1,96223951	1,659377359	1
Melastomataceae-Malvaceae	0,291294171	-2,428784978	3,01137332	1
Meliaceae-Malvaceae	0,160539593	-1,595263947	1,916343134	1
Moraceae-Malvaceae	-0,042690483	-2,762769632	2,677388665	1
Myrtaceae-Malvaceae	0,205015291	-1,945396091	2,355426672	1
Orobanchaceae-Malvaceae	-0,02864398	-2,179055361	2,121767402	1
Polygalaceae-Malvaceae	0,036540738	-2,683538411	2,756619887	1
Rubiaceae-Malvaceae	0,255145071	-1,544018172	2,054308315	1
Sapindaceae-Malvaceae	0,440025304	-1,068803133	1,948853742	1
Sapotaceae-Malvaceae	0,119759602	-1,679403641	1,918922845	1
Simaroubaceae-Malvaceae	0,412284203	-3,186042283	4,01061069	1
Siparunaceae-Malvaceae	0,139830573	-1,65933267	1,938993816	1
Vochysiaceae-Malvaceae	-0,080503086	-2,230914468	2,069908295	1
Meliaceae-Melastomataceae	-0,130754578	-2,73503209	2,473522934	1
Moraceae-Melastomataceae	-0,333984655	-3,665387641	2,997418333	1
Myrtaceae-Melastomataceae	-0,08627888	-2,971358497	2,798800737	1
Orobanchaceae-Melastomataceae	-0,319938151	-3,205017768	2,565141466	1
Piperaceae-Melastomataceae	0,532839271	-2,10086604	3,166544581	1
Polygalaceae-Melastomataceae	-0,254753433	-3,58615642	3,076649554	1
Rubiaceae-Melastomataceae	-0,0361491	-2,66985441	2,597556211	1
Salicaceae-Melastomataceae	0,356724719	-2,103679445	2,817128884	1
Sapindaceae-Melastomataceae	0,148731133	-2,295850332	2,593312599	1
Sapotaceae-Melastomataceae	-0,171534569	-2,80523988	2,462170742	1

Simaroubaceae-Melastomataceae	0,120990032	-3,959128691	4,201108755	1
Siparunaceae-Melastomataceae	-0,151463598	-2,785168909	2,482241713	1
Solanaceae-Melastomataceae	0,214885444	-2,236960767	2,666731655	1
Vochysiaceae-Melastomataceae	-0,371797257	-3,256876874	2,51328236	1
Moraceae-Meliaceae	-0,203230077	-2,807507589	2,401047435	1
Myrtaceae-Meliaceae	0,044475697	-1,957448351	2,046399746	1
Orobanchaceae-Meliaceae	-0,189183573	-2,191107621	1,812740475	1
Polygalaceae-Meliaceae	-0,123998855	-2,728276367	2,480278657	1
Rubiaceae-Meliaceae	0,094605478	-1,524165402	1,713376358	1
Sapindaceae-Meliaceae	0,279485711	-1,008921848	1,56789327	1
Sapotaceae-Meliaceae	-0,040779991	-1,659550871	1,577990889	1
Simaroubaceae-Meliaceae	0,25174461	-3,259862471	3,763351691	1
Siparunaceae-Meliaceae	-0,02070902	-1,6394799	1,59806186	1
Solanaceae-Meliaceae	0,345640022	-0,956498734	1,647778778	1
Vochysiaceae-Meliaceae	-0,24104268	-2,242966728	1,760881369	1
Myrtaceae-Moraceae	0,247705774	-2,637373843	3,132785391	1
Orobanchaceae-Moraceae	0,014046504	-2,871033113	2,899126121	1
Polygalaceae-Moraceae	0,079231221	-3,252171766	3,410634208	1
Rubiaceae-Moraceae	0,297835555	-2,335869756	2,931540865	1
Salicaceae-Moraceae	0,690709374	-1,769694791	3,151113538	1
Sapindaceae-Moraceae	0,482715788	-1,961865678	2,927297253	1
Sapotaceae-Moraceae	0,162450085	-2,471255225	2,796155396	1
Simaroubaceae-Moraceae	0,454974687	-3,625144036	4,53509341	1
Siparunaceae-Moraceae	0,182521057	-2,451184254	2,816226367	1
Solanaceae-Moraceae	0,548870098	-1,902976113	3,000716309	1
Vochysiaceae-Moraceae	-0,037812603	-2,92289222	2,847267014	1
Orobanchaceae-Myrtaceae	-0,233659271	-2,589316914	2,121998372	1
Polygalaceae-Myrtaceae	-0,168474553	-3,05355417	2,716605064	1
Rubiaceae-Myrtaceae	0,050129781	-1,989929581	2,090189142	1

Salicaceae-Myrtaceae	0,4430036	-1,367804835	2,253812034	1
Sapindaceae-Myrtaceae	0,235010014	-1,554240409	2,024260436	1
Sapotaceae-Myrtaceae	-0,085255689	-2,12531505	1,954803673	1
Simaroubaceae-Myrtaceae	0,207268913	-3,517352857	3,931890682	1
Siparunaceae-Myrtaceae	-0,065184718	-2,105244079	1,974874644	1
Solanaceae-Myrtaceae	0,301164324	-1,497998919	2,100327568	1
Vochysiaceae-Myrtaceae	-0,285518377	-2,64117602	2,070139266	1
Polygalaceae-Orobanchaceae	0,065184718	-2,819894899	2,950264335	1
Rubiaceae-Orobanchaceae	0,283789051	-1,75627031	2,323848413	1
Sapindaceae-Orobanchaceae	0,468669284	-1,320581139	2,257919707	1
Sapotaceae-Orobanchaceae	0,148403582	-1,89165578	2,188462943	1
Simaroubaceae-Orobanchaceae	0,440928183	-3,283693586	4,165549953	1
Siparunaceae-Orobanchaceae	0,168474553	-1,871584809	2,208533914	1
Solanaceae-Orobanchaceae	0,534823595	-1,264339649	2,333986838	1
Vochysiaceae-Orobanchaceae	-0,051859106	-2,407516749	2,303798537	1
Salicaceae-Piperaceae	-0,176114551	-1,551522292	1,199293189	1
Sapindaceae-Piperaceae	-0,384108137	-1,731006924	0,96279065	1
Simaroubaceae-Piperaceae	-0,411849238	-3,945335703	3,121637226	1
Solanaceae-Piperaceae	-0,317953827	-1,677993401	1,042085748	1
Rubiaceae-Polygalaceae	0,218604333	-2,415100977	2,852309644	1
Salicaceae-Polygalaceae	0,611478152	-1,848926012	3,071882317	1
Sapindaceae-Polygalaceae	0,403484566	-2,041096899	2,848066032	1
Sapotaceae-Polygalaceae	0,083218864	-2,550486447	2,716924175	1
Simaroubaceae-Polygalaceae	0,375743465	-3,704375257	4,455862188	1
Siparunaceae-Polygalaceae	0,103289835	-2,530415476	2,736995146	1
Solanaceae-Polygalaceae	0,469638877	-1,982207334	2,921485088	1
Vochysiaceae-Polygalaceae	-0,117043824	-3,002123441	2,768035793	1
Salicaceae-Rubiaceae	0,392873819	-0,982533922	1,76828156	1
Sapindaceae-Rubiaceae	0,184880233	-1,162018554	1,53177902	1

Sapotaceae-Rubiaceae	-0,135385469	-1,801086963	1,530316024	1
Simaroubaceae-Rubiaceae	0,157139132	-3,376347332	3,690625597	1
Siparunaceae-Rubiaceae	-0,115314498	-1,781015992	1,550386995	1
Solanaceae-Rubiaceae	0,251034544	-1,109005031	1,611074118	1
Vochysiaceae-Rubiaceae	-0,335648158	-2,375707519	1,704411204	1
Sapindaceae-Salicaceae	-0,207993586	-1,173043497	0,757056325	1
Simaroubaceae-Salicaceae	-0,235734687	-3,642010011	3,170540637	1
Solanaceae-Salicaceae	-0,141839275	-1,125146263	0,841467712	1
Sapotaceae-Sapindaceae	-0,320265702	-1,667164489	1,026633085	1
Simaroubaceae-Sapindaceae	-0,027741101	-3,422605085	3,367122883	1
Siparunaceae-Sapindaceae	-0,300194731	-1,647093518	1,046704056	1
Solanaceae-Sapindaceae	0,066154311	-0,876863463	1,009172084	1
Vochysiaceae-Sapindaceae	-0,520528391	-2,309778813	1,268722032	1
Simaroubaceae-Sapotaceae	0,292524601	-3,240961863	3,826011066	1
Siparunaceae-Sapotaceae	0,020070971	-1,645630522	1,685772465	1
Solanaceae-Sapotaceae	0,386420013	-0,973619561	1,746459587	1
Vochysiaceae-Sapotaceae	-0,200262688	-2,24032205	1,839796673	1
Siparunaceae-Simaroubaceae	-0,27245363	-3,805940095	3,261032834	1
Solanaceae-Simaroubaceae	0,093895412	-3,306203524	3,493994347	1
Vochysiaceae-Simaroubaceae	-0,49278729	-4,217409059	3,23183448	1
Solanaceae-Siparunaceae	0,366349042	-0,993690532	1,726388616	1
Vochysiaceae-Siparunaceae	-0,220333659	-2,260393021	1,819725702	1
Locations [b]				
Ma-Ko	-0.00801175	-0.4314406	0.4154171	1.0000000
Mc-Ko	-0.03089504	-0.4478716	0.3860816	0.9999998
Mo-Ko	2.38300425	1.3930768	3.3729317	0.0000000
Mt-Ko	-0.19788885	-1.1878163	0.7920386	0.9994729
Rg-Ko	-0.07121689	-0.5487204	0.4062867	0.9999418

Rm-Ko	-0.74348137	-2.6636283	1.1766656	0.9545730
Ro-Ko	-1.51482916	-4.2159971	1.1863388	0.7154648
Si-Ko	0.03027990	-0.3261796	0.3867394	0.9999993
Mc-Ma	-0.02288329	-0.4677662	0.4219997	1.0000000
Mo-Ma	2.39101600	1.3890142	3.3930178	0.0000000
Mt-Ma	-0.18987709	-1.1918789	0.8121247	0.9996452
Rg-Ma	-0.06320514	-0.5652619	0.4388516	0.9999842
Rm-Ma	-0.73546962	-2.6618693	1.1909301	0.9581631
Ro-Ma	-1.50681741	-4.2124338	1.1987989	0.7231976
Si-Ma	0.03829165	-0.3504431	0.4270264	0.9999977
Mo-Mc	2.41389929	1.4146069	3.4131916	0.0000000
Mt-Mc	-0.16699381	-1.1662862	0.8322985	0.9998617
Rg-Mc	-0.04032185	-0.5369490	0.4563053	0.9999995
Rm-Mc	-0.71258633	-2.6375781	1.2124054	0.9651629
Ro-Mc	-1.48393412	-4.1885482	1.2206800	0.7393738
Si-Mc	0.06117493	-0.3205216	0.4428715	0.9998993
Mt-Mo	-2.58089310	-3.9242739	-1.2375123	0.0000002
Rg-Mo	-2.45422114	-3.4802452	-1.4281971	0.0000000
Rm-Mo	-3.12648562	-5.2505572	-1.0024140	0.0002034
Ro-Mo	-3.89783341	-6.7475745	-1.0480923	0.0008297
Si-Mo	-2.35272436	-3.3283160	-1.3771327	0.0000000
Rg-Mt	0.12667196	-0.8993521	1.1526960	0.9999864
Rm-Mt	-0.54559252	-2.6696641	1.5784791	0.9968021
Ro-Mt	-1.31694031	-4.1666814	1.5328008	0.8810614
Si-Mt	0.22816874	-0.7474229	1.2037604	0.9983512
Rm-Rg	-0.67226448	-2.6112677	1.2667387	0.9766404
Ro-Rg	-1.44361227	-4.1582168	1.2709922	0.7712175
Si-Rg	0.10149678	-0.3455294	0.5485230	0.9986669
Ro-Rm	-0.77134779	-4.0619454	2.5192498	0.9983242

Si-Rm	0.77376126	-1.1390344	2.6865569	0.9416272
Si-Ro	1.54510905	-1.1508381	4.2410562	0.6904639

[a] W: water. PE: petroleum ether. M: methanol. EA: ethyl acetate

[b] Si: Sinnamary. Mo: Montsinéry-Tonnegrande. Rg: Régina. Mc: Macouria. Ma: Mana. Ko: Kourou. Mt: Matoury. Rm: Rémire-Montjoly. Ro: Roura

Declaration of interests

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: