

# Green Poison from The Tropics: *Annona muricata* As Natural Insecticides Solution

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## ABSTRACT

The massive use of synthetic insecticides in vector and pest control has caused various problems, including insect resistance, environmental pollution, and the risk of toxicity to non-target organisms. Therefore, the development of natural insecticides based on tropical plants is becoming a more environmentally friendly and sustainable strategic alternative. One plant with potential as a bioinsecticide is *Annona muricata* (soursop). The method used is a systematic review study on scientific publications for the period 2020–2025 that report data on toxicity (LC<sub>50</sub>), mortality, and safety against non-target organisms from various plant parts (seeds, leaves, and bark) against disease-vector insects, agricultural pests, and domestic insects. Data were analyzed descriptively to assess the effectiveness of insecticides based on plant parts, extract types, and target species. The review results show that *Annona muricata* has acetogenin with strong and broad-spectrum insecticidal activity. Insecticide activity has been reported against *Spodoptera frugiperda*, *Plutella xylostella*, *Bactrocera* sp., *Periplaneta americana*, *Culex* sp., *Aedes albopictus*, and *Rhipicephalus* spp., with mortality rates increasing as extract concentrations increase. Some studies have shown safe limits on non-target organisms at certain concentrations, indicating potential ecological selectivity. Formulation development, extract standardization, and advanced toxicity tests are still needed to optimize the application of *Annona muricata*-based bioinsecticides on a field scale.



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## INTRODUCTION

The main challenges in the field of environmental health and public health are still to date, one of which is vector and pest control. This problem mainly occurs in tropical regions with such high biodiversity, supported by a climate of insect development throughout the year. The widespread use of synthetic insecticides is effective in the short term, but on the other hand, it poses various negative impacts such as insect resistance, environmental pollution, and the risk of toxicity to non-target organisms and humans. This condition encourages the need for alternative innovations that are more environmentally friendly and sustainable, one of which is through the use of plant-based natural insecticides derived from tropical ecosystems (Aryani & Wahyuningsih, 2021; Benu et al., 2020a; Reyes-Ávila et al., 2024).

Indonesia, as a tropical country, has a wealth of flora that has great potential as a source of bioinsecticides, including soursop plants (*Annona muricata* L.), which are widespread and easy to cultivate. This plant is known to contain various secondary metabolites such as alkaloids, flavonoids, saponins, tannins, and especially acetogenin compounds that have high biological activity, including

as larvicides and natural insecticides. These bioactive compounds work by disrupting the metabolic system and detoxifying enzymes in insects, thereby causing larval death and inhibiting the development of vector insects. In addition, research by Marcellia et al. (2023) and Ahyanti & Yushananta (2023) states that *Annona muricata* has a fairly high content of Flavonoids and Saponins as natural ingredients that function as insecticides. The urgency of developing natural insecticides is also increasingly relevant in the context of controlling vectors of tropical diseases such as dengue, zika, and chikungunya transmitted by *the Aedes aegypti* mosquito. Vector control in the larval phase is an effective strategy to suppress mosquito populations before they reach the adult phase. From an ecological perspective, the use of plant-based insecticides such as *Annona muricata* is considered more sustainable than synthetic insecticides because they are biodegradable, more selective to the target, and have the potential to reduce the risk of environmental pollution. Furthermore, the use of "green poisons" from tropical plants such as *Annona muricata* is becoming increasingly strategic because, in addition to being easy to obtain, it also has relatively low production costs and can be developed as a local bioinsecticide product.

The problem of insect resistance to synthetic insecticides is increasing, as are the impacts of environmental pollution and the toxic impact of chemicals on humans and non-target organisms. Therefore, it is very important to investigate the potential of *Annona muricata* to be carried out. The continuous use of chemical insecticides has been reported to cause resistance to various disease vector species, such as *Aedes*, *Culex*, and *Anopheles* mosquitoes, resulting in a further decline in the effectiveness of vector control. On the other hand, Indonesia, as a tropical country, has biological wealth that has the potential to be developed as a source of environmentally friendly bioinsecticides, one of which is *Annona muricata*, which is known to contain bioactive compounds such as acetogenin, alkaloids, flavonoids, and saponins that have the potential to be toxic to insects (Akbar et al., 2023). Although various studies on the insecticide activity of these plants have been published, the available information is still scattered, diverse in methods, and has not been comprehensively synthesized. Therefore, this review is important to clarify the latest research developments, identify the effectiveness and mechanism of action of *Annona muricata*, and strengthen the scientific basis for its use as a safer, more sustainable, and relevant natural insecticide alternative in supporting environment-based vector control.

## METHOD

This study uses a literature review method with a systematic approach referring to the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The study was conducted to identify, select, and analyze scientific articles that discuss the potential of *Annona muricata* as a natural insecticide in the 2020–2025 publication period. The source of data for this research comes from published articles obtained through the internet from the databases of Google Scholar, Semantic Scholar, Garuda, PubMed, Science Direct, and SpringerLink.

The article search used a combination of keywords in the form of "*Annona muricata*", "natural insecticide", "botanical insecticide", "biolarvicide", "larvicidal activity", "mosquito control", and "plant-based insecticide". Keywords are combined using the Boolean AND and OR operators to obtain more specific and relevant search results. The inclusion criteria in this study include: (1) original research article, (2) published between 2020-2025, (3) discussing insecticide or larvicide activity of *Annona muricata*, (4) available in full text, and (5) published in Indonesian or English. Meanwhile, the exclusion criteria include literature review articles, proceedings, articles that do not have experimental data, duplicate articles, and research that does not specifically use *Annona muricata* as the main material.

The article selection stage is carried out based on the PRISMA flow diagram, which consists of identification, screening, *eligibility*, and inclusion of the final article. At the identification stage, all articles obtained from the database are collected, and duplicate articles are deleted. The *screening stage* is carried out by examining the title and abstract to assess the suitability of the research topic. Articles that pass the initial selection are then read in full (full-text review) at the *eligibility stage* to ensure compliance with the inclusion and exclusion criteria that have been set.

A risk assessment of bias was conducted to evaluate the methodological quality and reliability of the results of each article included in the study. This process aims to minimize the

possibility of systematic errors that can affect the validity of research results regarding the potential of *Annona muricata* as a natural insecticide. Bias assessment was conducted descriptively by adapting several experimental research quality indicators from the Joanna Briggs Institute (JBI) Critical Appraisal Tools and laboratory research evaluation guidelines. Each article was evaluated based on several main aspects, namely the clarity of the research objective, the suitability of the research design, the clarity of the extraction and treatment methods, the use of control groups, replication, and sample size, the clarity of data analysis, and the completeness of the reporting of the results. Each aspect of the assessment was categorized into low, medium, or high risk of bias. Articles with complete methods, clear use of controls, and adequate data analysis are categorized as having a low risk of bias. In contrast, articles with incomplete methodological information or no peer controls were categorized as having a higher risk of bias. The results of the bias assessment are used as a consideration in interpreting the strength of the scientific evidence from each study analyzed in this study.

## RESULTS

The process of identifying and selecting articles in this study was carried out using the PRISMA approach (Figure 1). Based on the results of searches from various scientific databases, a number of articles were obtained, which then went through several stages of screening. The results of the last screening obtained 11 articles that met the inclusion criteria and were suitable for analysis in this study in the 2020–2025 range.

The initial identification process was carried out through a search of several scientific databases using keywords related to *Annona muricata*, bioinsecticides, larvicides, plant insecticides, and vector control. From the search results, a number of articles were obtained, which were then selected based on the suitability of the title and abstract. The next stage is done by removing duplicate articles as well as articles that are not relevant to the focus of the research, such as studies that do not address insecticide activity, do not use *Annona muricata* as the main ingredient, or are not available in the full text. The remaining articles then undergo a thorough eligibility assessment process by considering inclusion criteria, including publications from 2020–2025, original research articles, the use of experimental methods, and discussions on the effectiveness of *Annona muricata* as a natural insecticide or larvicide agent.

The results of the 2020-2025 article screening on  $LC_{50}$  of *Annona muricata* simplicia extract against mosquito larvae gave different results regarding  $LC_{50}$  and zero values, but only 1 study reported on NOA. Table 1 shows that *Annona muricata* has strong, broad-spectrum insecticidal activity against a wide range of target species, both health vectors and agricultural pests, with varying effectiveness depending on the plant part, extract type, and concentration. Soursop seed extract was recorded to have high toxicity to *Aedes aegypti* larvae with a very low  $LC_{50}$  value (0.009 mg/mL), and was relatively safe against non-target organisms at certain concentrations. In addition, seed extracts with organic solvents as well as in spray formulations are reported to provide high mortality in test insects such as mealworms and crickets, demonstrating practical potential as a plant-based insecticide.

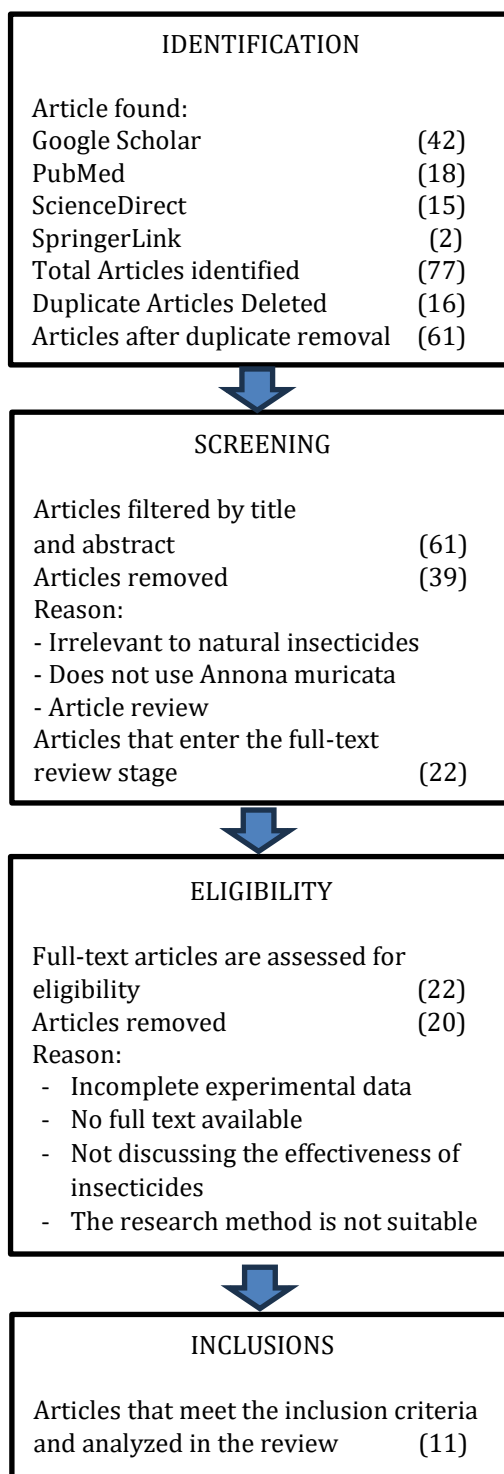


Figure 1. PRISMA flow diagram of the article selection process

Table 1. The potential of soursop plants as bioinsecticides

No.	Author (year)	Plant parts	Target species	LC <sub>50</sub> / Toxicity data	NOA (No observed adverse)
1.	Parthiban et al., (2020)	Seeds - kernel extract (0.9% saline)	<i>Aedes aegypti</i> (larva)	0.009 mg·mL <sup>-1</sup> (LC <sub>50</sub> ; ~18 h/reported threshold time).	Safe against <i>Chironomus costatus</i> up to ≤0.0028 mg·mL <sup>-1</sup> (24 h) in the same study.
2.	Irwan et al., (2021)	Seeds (n-hexane/ethanol)	<i>Tenebrio/</i>	LC <sub>50</sub> specific NR; High	NOA: NR (not reported in the article).

No.	Author (year)	Plant parts	Target species	LC <sub>50</sub> / Toxicity data	NOA (No observed adverse)
		extract) - spray formulation (blend)	mealworm, Gryllidae (crickets) — lab test	concentrations (e.g., 90% of composition) indicate the highest mortality (practical effectiveness results).	
3.	Khoirunnisya et al., (2022)	Leaves	<i>Spodoptera frugiperda</i>	A concentration of 60 g/L gives 50% mortality < 1 day; 85% mortality at 3 HSAs	No specifics mentioned
4.	Ningrum et al., (2023)	Leaves	<i>Bactrocera</i> sp. (fruit flies)	Concentration of 15% reduced mortality significantly (p<0.001); the LC <sub>50</sub> number was not reported	No specifics mentioned
5.	Ramadhan & Firmansyah, (2023)	Leaves	<i>Spodoptera frugiperda</i> (corn armyworm)	3% methanol extract caused larval mortality of 83.33 ± 5.77% and inhibited feeding 91.11%	Not reported
6.	Marcellia et al. (2023)	Leaves - ethanol extract (percolation)	<i>Aedes aegypti</i> (larva)	LC <sub>50</sub> = 0.163% (w/v) 3% concentration gives 100% mortality (small field/lab test).	NOA: NR (not reported in the article).
7.	Marisa & Melinda (2023)	Stem-bark - water extract/bark extract	<i>Periplaneta americana</i> (adult/cockroach)	LC <sub>50</sub> = 2.89% (formulation concentration; observation 24–72 h)	NOA: NR for aquatic organisms. The study focuses on cockroach mortality.
8.	Zakari et al., (2023)	Leaves - ethanol extract	<i>Rhipicephalus</i> spp. (Boophilus/cattle ticks, adult immersion)	LC <sub>50</sub> = 144.02 μL·mL <sup>-1</sup> (adult immersion test; observation time varied).	NOA: NR (acaricidal focus study).
9.	Rique et al., (2024)	Seeds - ethanol extract & microencapsulated ethanolic extract (MEE)	<i>Plutella xylostella</i> (larva, ingestion)	Ethanol extract LC <sub>50</sub> = 0.204 g·L <sup>-1</sup> ; MEAT LC <sub>50</sub> = 0.114 g·L <sup>-1</sup> (the author also reported LC <sub>99</sub> /LC <sub>99</sub> values). (unit = g·L <sup>-1</sup> ≡ mg·mL <sup>-1</sup> ).	Studies also evaluate microstructure & stability; There are test reports on non-targets

No.	Author (year)	Plant parts	Target species	LC <sub>50</sub> / Toxicity data	NOA (No observed adverse)
10.	Rinto et al., (2025)	Leaves	<i>Aedes aegypti</i> & <i>Culex</i> sp. (mosquito larvae)	Literacy in the article said it was effective at 5,000 ppm ( <i>Aedes aegypti</i> ) in 90 minutes and 1.25% ( <i>Culex</i> sp.) in 8 hours.	Not reported
11.	Ramadhan & Yuliani, (2025)	Combined Leaves and Seeds	<i>Spodoptera frugiperda</i>	A combined 40% concentration resulted in a mortality of 96.67%	No specifics mentioned

Soursop leaf extract also shows significant effectiveness, especially against mosquito larvae and agricultural pests. An LC<sub>50</sub> value of 0.163% for *Aedes aegypti* and a mortality of up to 100% at a concentration of 3% indicates a high larvicide potential. In *the pest Spodoptera frugiperda*, leaf extract is able to cause 50–85% mortality in a short time and significantly inhibit feeding activities. Insecticide activity has also been reported against *Bactrocera* sp., *Culex* sp., and *Aedes albopictus*, with a range of LC<sub>50</sub> indicating effective toxicity at relatively low concentrations.

Other parts, such as stem bark and leaf and seed extract combinations, also showed effectiveness against domestic insects and pests, for example, LC<sub>50</sub> 2.89% against *Periplaneta americana* and mortality of up to 96.67% for *Spodoptera frugiperda* in combination formulations. Formulation innovations such as microencapsulation have also been shown to improve efficacy, with a decrease in LC<sub>50</sub> values in *Plutella xylostella* compared to conventional extracts. Overall, these findings confirm that *Annona muricata* has high potential as a multi-target bioinsecticide that is effective at relatively low concentrations and supports the development of environmentally friendly natural insecticides.

## DISCUSSION

The results of this review demonstrate that *Annona muricata* possesses significant potential as a plant-based insecticide against a wide range of target organisms, including mosquito larvae, agricultural pests, household insects, and ectoparasites. Nearly all parts of the plant, particularly the seeds and leaves, have been reported to exhibit insecticidal activity. The relatively low LC<sub>50</sub> values observed in several studies indicate strong biological toxicity, thereby reinforcing the concept of “green poison” derived from tropical plants as a safer and more sustainable alternative to synthetic insecticides.

These studies support that soursop leaf extract has high effectiveness as a larvicide, even at certain concentrations, is able to produce *Aedes aegypti* larval mortality of up to 100%, and has a low LC<sub>50</sub>, indicating significant potential toxicity to vectors. In addition, various extracts from the Marcellia et al. (2023) *plant parts of Annona muricata*, including seeds and leaves, have been shown to show larvicide activity against several important mosquito species such as *Aedes aegypti*, *Anopheles stephensi*, and *Culex quinquefasciatus* (Parthiban et al., 2020).

Among the various plant parts, soursop seeds consistently showed the highest insecticidal potency. This finding is strongly associated with the high concentration of acetogenin compounds, especially annonacin, which are recognized as the principal bioactive constituents of *Annona muricata*. Previous studies reported that annonacin exhibited very strong larvicidal activity against *Aedes aegypti* and *Aedes albopictus*, with LC<sub>50</sub> values in the microgram-per-milliliter range. Rodrigues et al. (2021) reported an LC<sub>50</sub> value of 2.65 µg/mL against *Ae. Aedes aegypti*, indicating remarkable toxicity even at low concentrations. Similarly, seed extracts prepared using organic solvents such as ethanol and chloroform demonstrated enhanced larvicidal activity due to their higher efficiency in extracting lipophilic acetogenins. Some studies even reported LC<sub>50</sub> values

below 1 µg/mL in acetogenin-rich fractions, confirming the strong bioactivity of soursop seed extracts against mosquito larvae and agricultural pests such as *Plutella xylostella* (Rique et al., 2024).

Although the insecticidal activity of soursop leaves was generally lower than that of the seeds, leaf extracts still exhibited substantial larvicidal effects. Several studies demonstrated that soursop leaf extracts were capable of causing high mortality in *Aedes aegypti* larvae, reaching up to 100% mortality at certain concentrations. The effectiveness increased proportionally with concentration, with LC<sub>50</sub> values generally reported in the range of hundreds of ppm. Marcellia et al. (2023) also reported that leaf extract concentrations around 0.163% produced significant larval mortality. These findings indicate that leaves remain a promising and practical source of botanical insecticides because they are more readily available and easier to process compared to seeds.

The insecticidal efficacy of *Annona muricata* is closely related to its biochemical and physiological mechanisms of action. Acetogenin compounds primarily act by inhibiting mitochondrial complex I in the electron transport chain, resulting in disruption of ATP synthesis and cellular energy depletion. This mechanism eventually leads to paralysis and death of the target insects. In addition to mitochondrial disruption, soursop extracts were also reported to inhibit detoxification enzymes such as esterases and proteases in mosquito larvae, thereby impairing xenobiotic metabolism and increasing susceptibility to toxic compounds (Santos et al., 2023).

These biochemical disturbances explain the physiological alterations observed in exposed larvae, including reduced feeding activity, abnormal movement, morphological damage, and eventual mortality. Morphological abnormalities reported in previous studies further suggest that *Annona muricata* exerts both neurotoxic and systemic physiological effects on insects (Smith & Shejwalkar, 2020). Another important finding of this review is the broad-spectrum insecticidal activity of *Annona muricata*. The extracts were effective not only against disease vectors such as *Aedes aegypti*, *Anopheles stephensi*, and *Culex quinquefasciatus*, but also against agricultural pests, including *Spodoptera frugiperda* and *Plutella xylostella*, household pests such as *Periplaneta americana*, and ectoparasites like *Rhipicephalus* spp. This wide target range indicates that the secondary metabolites of *Annona muricata* act on multiple physiological sites, which is an important characteristic of modern botanical insecticides. Such multi-target activity may also reduce the likelihood of rapid resistance development compared with single-target synthetic insecticides. Moreover, the ability of soursop extracts to affect multiple mosquito genera simultaneously supports their potential application in Integrated Vector Management (IVM) programs, particularly in tropical regions where vector-borne diseases remain endemic (Parthiban et al., 2020).

In terms of environmental safety, several studies reported relatively low toxicity of *Annona muricata* extracts toward non-target aquatic organisms such as *Chironomus costatus*, suggesting a degree of biological selectivity. This characteristic represents a major advantage over many conventional synthetic insecticides, which often exhibit broad non-selective toxicity and contribute to environmental contamination. The effectiveness of acetogenin-rich fractions at low concentrations also indicates the possibility of achieving efficient vector control with reduced ecological risk. Nevertheless, most studies included in this review did not comprehensively evaluate No Observed Adverse Effect (NOA) levels, particularly in vertebrates and beneficial ecosystem organisms. Therefore, further toxicological investigations, including chronic toxicity and ecotoxicity assessments, are essential before large-scale field implementation can be recommended.

The review also highlights the critical influence of extraction methods and formulation technologies on insecticidal efficacy. Organic solvent extracts, particularly ethanol, methanol, and chloroform extracts, generally demonstrated higher activity than aqueous extracts because these solvents are more effective in extracting lipophilic acetogenins (Syahputra & Ginting, 2024).

Some of the studies in the review report safe limits on aquatic non-target organisms such as *Chironomus costatus*, suggesting that soursop extract has a certain biological selectivity. This is a major advantage over synthetic insecticides that tend to be non-selective and pollute the environment. Toxicity research also confirms that the use of low concentrations of acetogenin fractions can provide high larvicide effects with less ecological risk (Parthiban et al., 2020).

This approach is in line with the concept of Integrated Vector Management, which emphasizes the use of local resources and appropriate technologies that are safe for the

environment. The study also confirms that key bioactives such as annonacin found in soursop seeds have strong larvicide activity and are able to inhibit the metabolic enzymes of mosquito larvae, thereby strengthening the potential for the development of effective and environmentally friendly plant-based insecticide products (Rodrigues et al., 2021). Furthermore, several studies emphasized the advantages of advanced formulation approaches such as microencapsulation. Microencapsulation technology enhances the stability, protection, and bioavailability of active compounds, thereby increasing larvicidal efficiency at lower doses and improving storage stability (Srivastava et al., 2024). These innovations are highly relevant for the practical development of tropical plant-based bioinsecticides suitable for field applications.

The findings of this review confirm that *Annona muricata* is a very promising candidate for the development of natural insecticides. Its effectiveness is supported by the presence of potent bioactive compounds such as acetogenins, low  $LC_{50}$  values across multiple target species, multi-site mechanisms of action, and relatively favorable environmental safety profiles compared with synthetic insecticides. In the context of environmental health and vector control in tropical countries such as Indonesia, the utilization of soursop-based insecticides is particularly strategic due to the plant's abundance, ease of cultivation, and local availability. Consequently, *Annona muricata* has strong potential to be developed into sustainable local bioinsecticide products that support environmentally friendly pest and vector management strategies.

Despite these promising findings, several challenges remain. Most existing studies are still laboratory-based and use varying extraction methods, formulations, and bioassay protocols, making direct comparisons difficult. Standardization of extraction procedures, dosage formulations, and toxicity assessment methods is therefore required to strengthen the scientific evidence and facilitate commercialization. Future research should focus on chronic toxicity testing, field-scale efficacy trials, formulation optimization, and assessment of long-term environmental impacts. Such efforts are necessary to support the integration of *Annona muricata* into ecological-based vector and pest control programs aligned with the principles of Integrated Vector Management and sustainable environmental health practices (Irwan et al., 2021).

## CONCLUSION

Based on a study of eleven studies during the period 2020–2025, it can be concluded that *Annona muricata* simplicia extract, especially from leaves and seeds, shows strong potential as a bioinsecticide against mosquito larvae, especially *Aedes aegypti* and *Culex* sp. The low  $LC_{50}$  value, which is between 0.163% to 0.736%, proves that the toxicity of this extract is effective in killing larvae at various exposure times. The content of active compounds such as acetogenin, flavonoids, alkaloids, and saponins is thought to play a role in the mechanism of toxicity to the target insect. However, data on the value of NOA on non-target organisms is still very limited and requires further research to ensure their ecological safety. Further research is needed to identify the NOA or NOAEL value of soursop extract against non-target organisms such as fish, shrimp, and other aquatic macroinvertebrates to ensure environmental safety. It is recommended to conduct stability and formulation tests, so that soursop extract can be applied in the form of ready-to-use larvicides with a good shelf life and consistent effectiveness.

## AUTHOR'S DECLARATION

### Authors' contributions and responsibilities

**MA:** Writing original draft, visualization, conceptualization; **ES:** Writing original draft (supporting); **PY:** Supervision (lead), validation (equal), visualization (equal).

### Availability of data and materials

All data are available from the authors.

### Competing interests

The authors declare no competing interests.

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