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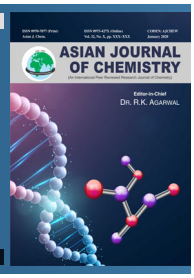

REVIEW

Insecticidal and Repellant Activities of Southeast Asia Plants towards Insect Pests: A Review

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Crops are being damaged by several plant pests. Several strategies have been developed to restrict the damage of cultivated plants by using synthetic pesticides and repellants. However, the use to control these insects is highly discouraged because of their risks on humans. Therefore, several alternatives have been developed from plant extracts to protect crops from plant pests. Accordingly, this review focuses on outlining the insecticidal and repellant activities of Southeast Asia plants towards insect pests. Several extracts of plants from Southeast Asia were investigated to explore their insecticidal and repellant activities. *Azadiracha indica* (neem) and *Piper* species were highly considered for their insecticidal and repellant activities compared to other plants. This review also addressed the investigation on extracts of other plant species that were reported to exert insecticidal and repellant activities. Most of the conducted studies have been still in the primarily stage of investigation, lacking a focus on the insecticidal and repellant spectrum and the identification of the active constituents which are responsible for the insecticidal and repellant activity.

Keywords: Insecticides, Repellants, Pests, Phytochemicals, Southeast Asia.

INTRODUCTION

Plant pests are organisms that attack and infest plants [1]. This includes animal pests (insects, nematodes, mites and rodents), plant pathogens (viruses, bacteria and fungi) and weeds [2]. Plant pests do not only interfere with the growth of the wild plants but also cultivated plants destroying nearly 30-40% of the annually cultivated plants worldwide [3]. Damage to plants by pests could take several aspects including a damage to the foliage, reducing the vitality of plants [1], direct feeding and causing infestation sites on crops through which pathogens invade to establish infestation. In tropical regions (*e.g.*, in Asia, Africa and South America), crops are being damaged by several plant pests mainly through direct feeding [4]. Therefore, it is undoubtedly that insects are the most devastating pest and a threat to the agriculture production, hence, strategies to eliminate them is necessary.

Several strategies have been developed to terminate or even restrict the damage of cultivated plants by pests to enhance the agricultural production for food security as human population increasing. One of the conventional strategies suggested by Sharp and Hallman [5] is a quarantine treatment by which method of irradiation, fumigation, cold and temperature was employed for crops during the preharvest, postharvest, distribution and storage processes to prevent exotic pest from invading or entering a certain geography. Other alternatives include the use of pesticides or repellant through the use of chemical compounds to prevent or terminate pests infestations or attacks [2,6,7]. However, their use to control these insects is highly discouraged due to the risk on human being [8]. Another strategy

is through genetic modificaqtion of plant genome by evoking plant resistance is one of the effective strategies to overcome this problem by producing transgenic plants (genetic engineering modification) that resist diseases caused by plant pests [9]. In addition, a greener and safer alternative have been developed from the plant kingdom through the utilization of plant extracts to terminate and to protect plant from plant pests [10]. This review focused on outlining the insecticidal and repellant activities of Southeast Asia plants towards insect pests.

Methodology: The survey strategy of research articles depended on searching the literature to identify studies that related to the insecticidal and repellant activities of Southeast Asia plants using different keywords including; "insecticidal activity" and "Southeast Asia plants" or alternatively; "repellant activities and Southeast Asia plants". Only studies that are related to the insecticidal and repellant activities plants in Southeast Asia countries (Malaysia, Indonesia, Thailand, Vietnam and Philippines) were included. The time of publication was excluded because the field of this study was not widely covered and limited source of literature.

Insecticidal and repellant activities of plant extracts

***Piper* species:** A mixture of water extracts of *Piper retrofractum* and *Annona squamosa* was found to exert an insecticidal activity against the population of *Crocidolomia pavonana* (F.) and *Plutella xylostella* (L.) that are attacking cabbage crop. This could be related to the insecticidal activity of piperamide in *Piper retrofractum* seeds as well as acetogenin compounds such as annonin I and squamosin in the twigs of *Annona squamosal* [11]. However, *n*-hexane, dichlormethane, ethylacetate and ethanol extracts of leaves of *Piper retrofractum* showed a marked insecticidal activity against diamondback moth *Plutella xylostella* than *P. nigrum.* However; the active constituent of interest was not identified [12]. In addition, the hexane extract of the essential oils of fresh fruit of *Piper nigrum* could induce a severe growth inhibition against the second instar of the larvae of *Spodoptera litura* due to its antifeedant activity, which could be related to the content of limonene, β-pinene and linalool [13], while the extract of *Piper aduncum* showed an adulticidal activity against the housefly *Musca domestica* [14]. In addition, the essential oils that were obtained from fresh fruits of black pepper (*Piper nigrum* L.) showed a larvicidal activity against the rice weevil (*Sitophilus oryzae)* and rice moth (*Corcyra cephalonica)*, which could be related to insecticidal activity of constituents of the essential oil including α-pinene, β-pinene, β-myrcene, limonene and caryophyllene [15]. The chloroform extract of whole plant of *Piper longum* showed a chromosome compactness against the salivary gland chromosomes of 3rd instar larvae of housefly (*Musca domestica* L), however, no phytochemical investigation was conducted the active constituents of interest [16] (Table-1).

Neem (*Azadirachta* species): The acetonic extracts of neem seeds showed a strong insecticidal activity against the second instar larvae of *Crocidolomia binotalis* Zellar mainly through inhibiting feeding [17]. Meanwhile the application of soil drench of *Azadiracha indica* (neem) was also found to be useful for the control of silverleaf whitefly (*Bemisia tabaci*) [18]. In Vietnam, fumigation of stored grain with natural neem oil (*Axadirachta indica* A. Juss) showed a repellant activity against maize weevil (*Sitophilus zeamais*) [19]. However, spraying the mango tree with the ethanolic extracts of *Azadirachta indica* L. (neem) showed a repellant activity against the gold dust beetle (*Hypomeces squamosus* L.) [20]. The extract of neem seeds could reduce the number of *Nephotettix virescens* D, *Nilaparvata lugens* S, *S. incertulas* and *Leptocorisa oratorius* on rice plant [21] (Table-2).

The methanolic extract of *Azadirachta excelsa* wood, which is native to Malaysia, Indonesia and Philippines, showed an insecticidal activity through antifeedant effect and growth inhibition against the larvae of *Crocidolomia binotalis* [22]. However, the *Azadirachta indica* is the species that was widely investigated for its insecticidal activity. In fact, neem extract was reported earlier to exert a potent antifeedant activity against some insects [23]. Perhaps the insecticidal, repellant and antifeedants of *Azadirachta indica* was attributed to its active constituents; Azadirachtin and di-*n*-propyl disulfide [24,25]. In fact, *Azadirachta indica* is a promising plant cultivar in Southeast Asia that was reported to be an effective botanical insecticidal and repellant activity, however, its safety should be studied.

***Annona* species:** *Annona* species were also investigated for their insecticidal activity so that the mixed extract of *Annona squamosa* and *Piper retrofractum* as well as mixed extracts

TABLE-1
INSECTICIDAL AND REPELLANT ACTIVITIES OF *Piper* SPECIES

Botanical name	Region	Part	Solvent	Active constituent (s)	Activity	Insects	Ref.
Piper retrofractum	Indonesia	Seeds	Methanol	Piperamide	Insecticidal activity	*Crocidolomia pavonana* (F.) and *Plutella xylostella* (L.)	[11]
Piper nigrum	Malaysia	Fresh fruit	Hexane	Limonene, β-pinene and linalool	Larvicidal activity	Larvae of *Spodoptera litura*	[13]
Piper nigrum L	Malaysia	Fresh fruits	Water	α-Pinene, β-Pinene, β-Myrcene, Limonene and Caryophyllene	Larvicidal activity	Larvae of Rice weevil, (*Sitophilus oryzae*) and rice moth (*Corcyra cephalonica)*	[15]
Piper longum	Malaysia	Whole plant	Chloroform	–	Insecticidal activity	Housefly (*Musca domestica* L)	[16]
Piper retrofractum	Thailand	Leaves	Hexane, dichloro-methane, ethylacetate and ethanol	–	Insecticidal activity	Diamondback moth (*Plutella xylostella)*	[12]
Piper aduncum	Malaysia	Leaves	Water	–	Adulticidal activity	Housefly (*Musca domestica)*	[14]

TABLE-2
INSECTICIDAL AND REPELLANT ACTIVITIES OF NEEM

Botanical name	Region	Part	Solvent	Active constituent (s)	Activity	Insects	Ref.
Azadirachta excelsa	Indonesia, Malaysia and Philippines	Wood	Methanol	–	Insecticidal activity	Larvae of *Crocidolomia binotalis*	[22]
Azadirachta indica	Indonesia	Seeds	Acetone	–	Insecticidal activity	Second instar larvae of *Crocidolomia binotalis* Zellar	[17]
Azadiracha indica	Malaysia	Soil drench	Water	–	Insecticidal activity	Silverleaf whitefly (*Bemisia tabaci*)	[18]
Azadirachta indica A. Juss	Vietnam	Seed	–	Azadirachtin	Repellant activity	Maize weevil bugs (*Sitophilus zeamais*)	[19]
Azadirachta indica L.	Malaysia	Leaves	Ethanol	–	Repellant activity	Gold dust beetle (*Hypomeces squamosus L.*)	[20]
Azadiracta indica	Indonesia	Seed	Water	–	Insecticidal activity	*Nephotettix virescens* D, *Nilaparvata lugens* S, *S. incertulas* and *Leptocorisa oratorius*	[21]

Aglaia odorata and *Annona squamosa* were found to exert an insecticidal activity against *Crocidolomia pavonana* (F.) (Lepidoptera: Pyralidae) and *Plutella xylostella* (L.) (Lepidoptera: Yponomeutidae) which attack cabbage [11]. On the other hand, the ether soursop leaf extract of *Annona muricata* L. was reported to have antifeeding activity against the fifth-instar larvae of *Spodoptera litura* F. However, its efficacy of converting the digested food, digestibility and peritrophic membrane structure were not significantly affected [26] (Table-3).

***Aglaia* species:** *Aglaia* species were also investigated for its insecticidal and repellant activity. The seed extracts of *Aglaia harmsiana* and *Aglaia odoratissima* showed a strong antifeedant insecticidal activity against the second instar larvae of *Crocidolomia binotalis* Zellar similar to the extracts of *Dysoxylum mollissimum* and *Trichilia trijuga* [17]. However, the insecticidal spectrum of extract of *Aglaia odoratissima* could be wider than that of *Aglaia harmsiana* since its extract was also found to be an effective antifeedant against the larvae of *Peridroma saucia.* The active component of (-)-rocaglamide that was isolated could hold a similar activity to the extract of *Aglaia harmsiana* [27] (Table-3).

***Aloe vera*:** *Aloe vera* is a plant belonging to the family Liliaceae of which leaves are filled with a gel-like content [28]. Few reports are available in the scientific literature about the insecticidal and repellant activity of *Aloe vera* in Southeast Asia countries. The Southeast plant should be more investigated for its insecticidal and repellant activity particularly its hydrogel of leaves which contains for at least 200 bioactive constituents that could be a promising candidate plant of having broad spectrum biological activities [29]. Nevertheless, the biological activity of each plant must be attributed due to its phytochemical composition [30]. Regardless of the considerable medicinal value of *Aloe vera* in treating several diseases [31-33], this plant was reported elsewhere to possess an insecticidal activity [34,35]. For example, a study from Thailand indicated that *Aloe vera* possess an acaricide activity against *Tetranychus cinnabarinus* [36]. On the other hand, a study from Malaysia indicated that extract of *Aloe vera* which was formulated as a mosquito coil was reported to exert repellant activity against *Aedes aegypti* [37] (Table-3).

Miscellaneous: Several Southeast Asia plants were investigated for their insecticidal and repellant activities including the essential oil of the fresh leaves of *Citrus hystrix* (Malaysian species) which were reported to be effective insecticide against the larvae of *Spodoptera litura* due to its antifeedant activity [38]. Furthermore, essential oils of *Mentha piperita* L. were found to be have a larvicidal activity against the rice weevil, *Sitophilus oryzae* and the rice moth *Corcyra cephalonica* [15]. Several Malaysian cultivars such as *Calotropis procera*, *Derris indica*, *Ipomoea quamoclit* and *Polygonum hydropiper* were reported to produce intense insecticidal activity against the salivary gland chromosomes of housefly *Musca domestica* L. (Diptera: Muscidae) [16]. Similarly, the essential oils of Thai clove (*Syzygium aromaticum*) exerted an insecticidal activity (larvicidal and oviposition deterrent) and repellant activities against housefly [39]. However, spraying the mango tree with the ethanol extracts of *Capsicum frutescent* L. (hot chilly) showed a repellant activity against *Hypomeces squamosus* L. (gold dust beetle) [20]. The acethonilic crude extract of leaves of *Ipomoea cairica* showed a larvicidal activity against *Culex quinquefasciatus* [40]. The dichloromethane extracts of the dried stem of *Bauhinia scandens* var. *horsfieldii* showed insecticidal activity against the second instar larvae of moth *Plutella xytostella* [41] (Table-3).

Plant insecticidal activity from a medicinal point of view: Basil (*Ocimum basilicum*) grows as a yearly crop in the temperate areas and it is also native to Southeast Asia. The quality and quantity of essential oil of this plant relies on seasonal variation, the harvest methods, the stage of leaf development, climate and the type of soil [42]. Although the Thai cultivar of *Ocimum basilicum* showed a repellant activity against the diamondback moth *Plutella xylostella* [43], it's essential oils showed a repellant and a potent larvicidal activities against mosquitoes [44]. However, the essential oils obtained from the Thai cultivar *Ocimum basilicum* was found to be not effective insecticide against *Aedes aegypi* [45,46]. Whereas, the Malaysian cultivar of *Ocimum basilicum* showed a potent larvicidal activity against the larvae of *Anopheles* mosquitoes [47]. Maybe the difference in the extraction methods, solvent of extraction or the phytochemical composition could be the plausible explanation for the contrasting findings in basil plants species. In the same line, the essential oils of several Southeast Asia plants including *Cinnamomum impressicostatum* Kosterm, *Cinnamomum microphyllum* Ridl. and *Curcuma domestica* Valeton showed a larvicidal activity against the larvae of *Aedes aegypti* while *Garcinia praniana* King, *G.*

TABLE-3
INSECTICIDAL AND REPELLANT ACTIVITIES OF SEVERAL PLANTS

Botanical name	Region	Part	Solvent	Active constituent (s)	Activity	Insects	Ref.
Annona squamosa and *Piper retrofractum*	Indonesia	Twigs	Methanol	Acetogenin compounds such as annonin I and squamosin	Insecticidal activity	*Crocidolomia pavonana* (F.) and *Plutella xylostella* (L.)	[11]
Annona muricata L.	Indonesia	Leaf	Ether	–	Insecticidal activity	Fifth-instar larvae of *Spodoptera litura* F,	[17,26]
Aglaia odoratissima	Indonesia	Seeds	Acetone	–	Insecticidal activity	The second instar larvae of *Crocidolomia binotalis* Zellar	[17]
Aglaia harmsiana	Indonesia	Seeds	Acetone	–	Insecticidal activity	The second instar larvae of *Crocidolomia binotalis* Zellar	[17]
Aglaia odoratissima	Thialand	Ground leaves	Methanol	(-)-Rocaglamide	Insecticidal activity	Larvae of *Peridroma saucia*	[27]
Aloe vera	Thailand	Leaves	Acetone	–	Acaricide activity	*Tetranychus cinnabarinus*	[36]
Citrus hystrix	Malaysia	Fresh levees	Water	β-Citronellal, β-citronellol linalool and citronellol	Insecticidal activity	*Spodoptera litura*	[38]
Mentha piperita L.	Malaysia	Fresh herbage	Water	Menthol, Limonene, Isomenthone, Cyclohexanone, 5-methyl-2-(-,ethylethyl)-, Isomenthol acetate and Cineole	A larvicidal activity	Rice weevil, *Sitophilus oryzae* and the rice moth, *Corcyra cephalonica*	[15]
Calotropis procera	Malaysia	Root bark	Chloroform	–	Insecticidal activity	Housefly *Musca domestica* L. (*Diptera: Muscidae*)	[16]
Derris indica	Malaysia	Seeds	Chloroform	–	Insecticidal activity	Housefly (*Musca domestica* L.)	[16]
Ipomoea quamoclit	Malaysia	Whole plant	Chloroform	–	Insecticidal activity	Housefly *Musca domestica* L. (*Diptera: Muscidae*)	[16]
Polygonum hydropiper	Malaysia	Whole plant	Chloroform	–	Intense insecticidal activity	Housefly *Musca domestica* L. (*Diptera: Muscidae*)	[16]
Syzygium aromaticum	Thailand	Ready essential oil	–	–	Insecticidal and repellant activities	Housefly	[39]
Capsicum frutescent L.	Malaysia	Fruit	Ethanol	–	A repellant activity	*Hypomeces squamosus* L. (gold dust beetle)	[20]
Ipomoea cairica	Malaysia	Leaves	Acetone	–	Larvicidal activity	*Culex quinquefasciatus*	[40]
Bauhinia scandens var. *horsfieldii*	Thailand	Dried stem	Dichloro-methane	Heptacosane and hexacosane	Insecticidal activity	The larvae of moth *Plutella xytostella* (second instars	[41]

griffithii T. Anders, *Labisia pumila* var. *alata* Lindl., *L. pumila* var. *pumila* and *Mitragyna speciosa* Korth. showed relatively high activity, but, their methanolic extracts were less effective [48]. Similarly, a Malaysian cultivar of *Melicope subunifoliolata* was reported to have a powerful feeding deterrent activity against the insect *Sitophilus zeamais* and a significant larvicidal activity against *Aedes aegypti* [49]. However, the methanolic extract of *Litsea elliptica* Blume was the most potent extract against adult of *Aedes aegypti* (L.) [50]. The crude extract of *Artemisia annua* reported to be effective against *Aedes aegypti* and *Anopheles sinensis* through producing oviposition deterrent and repellency activities [51]. Furthermore, the crude leaf extract of *Mangifera indica* was very effective in killing larvae of *Aedes aegypti* mosquitoes, while crude extracts of *Gluta renghas* and *Melanochyla fasciculiflora* were less effective [52]. These studies could shift investigating the interest of *Ocimum basilicum* in controlling plant pests to its medicinal value of minimizing the prevalence and incidence of dengue.

Bioactive insecticidal-repellant constituents: Plants are not only have special interest in the production of medicines or developing new medicines, but also as a source of bioinsecticides (plant extracts or pure compounds isolated from plants) [53]. Botanical insecticides could provide a protection for plants against pests through several activities including the interference with growth, feeding or reproduction of pests, disruption of mating of pest or attract pests to be killed [54].

There are two types of insecticides; namely, nonconventional (botanical insecticides) and conventional ones (synthetic insecticides). The conventional insecticides denote those synthetic chemical compounds which are used to protect plants form insects [55]. Over 900 synthetic pesticidal compounds are currently available in the market worldwide which are structurally different [56] belonging to several chemical classes,

such as organochlorines, organophosphates, carbamates, pyrethroids and neonicotinoids [55]. Although conventional insecticides are characterized by ease of use, speed of action and low cost [55], they are of a potential environmental hazards for birds, fish, bees and their accumulation in honeybee [56]. In addition, conventional insecticides exerts an elucidating effect on the secondary metabolites of crops which could induce the synthesis of toxins by plants [56].

Nonconventional insecticides denote either plant extracts or plant-isolated pure compounds which have insecticidal activity [54]. Therefore, botanical pesticides should be distinguished from microbial pesticides which are active against viruses, bacteria, fungi, protozoa or algae [54].

Historically, botanical insecticides were previously used for plant pest control before the invention of synthetic pesticides in the developed countries by the 30s of the last century [57]. In fact, botanical insecticides have been introduced in the field of enhancement plant productivity as an alternative to the conventional synthetic pesticides of which toxicity has been evoked [58]. Regardless of the efficacy of botanical insecticides and their spectrum of activity, they have biological advantages of low toxicity, minimum environmental effects and selectivity toward certain vertebrae other than conventional ones. However, botanical insecticides have certain limitations, such as low and inconsistent production unable to meet the market need [54,57]. In addition, the residual of the botanical insecticides could not be preserved because their liability to deterioration due to exposure to air and elevated temperature [53]. Moreover, there are difficulties in standardization of botanical insecticides as they comprised of several constituents compared to synthetic insecticides, whereby comprised mixture from an individual chemical component [53].

Compared to synthetic insecticides, botanical insecticides are comprised from several constituents [53]. As a matter of fact, botanical insecticides exist within the whole classes of secondary metabolites of plants (alkaloids, phenolics and terpenoids) [53]. However, several pure components that may possess insecticidal activity could be isolated from plants. Unfortunately, the active constituents in plant extract to which the insecticidal and/or repellant activity were not identified (Tables 1-3). Even if the active constituents of some plant extracts that exert insecticidal and/or repellant activities, future prospects of investigations should consider the activities of those identified constituents to be elucidated individually to specify which constituent was responsible for the insecticidal and/or the repellant activity.

Although *Piper* species were characterized by the presence of self-defense against most plant pests due to their content of lignans and isobutyl amides [59], another study suggested that the piperamides which were isolated from *Piper nigrum* could act as neurotoxins for the insects by modifying the axonal excitability [60,61]. Nonetheless, mechanisms of the insecticidal activity of piper species need to be further investigated. In addition, further studies on the insecticidal activities of piper species should be conducted to investigate their spectrum of insecticidal activities taking into consideration using of several extraction solvents, several parts of the plant with the identification of the active constituents in each extract.

Some active constituents of plant extracts were well-specified to exert insecticidal or repellant activities. For example, acetogenins (from edible fruit of *Annona muricate)* were reported to be effective insecticides that are produced annually in tons in Philippines [57,62], while azadirachtin and di-*n*-propyl disulfide (from the seeds of *Azadirachta indica)* were reported to be an effective botanical insecticides, repellants and antifeedants [24,25]. Like azadirachtin, methyl eugenol as a pure constituent was reported to exert an insecticidal activity against rice insects (*Cnaphalocrocis medinali*, *Cyrtorhinus lividipennis)* [63]. Similarly, 1-cinnamoylmelianolone and 1-cinnamoyl-3,11-dihydroxymeliacarpin (from the fruit of *Melia zedarach)* were reported to be effective botanical insecticide [24]. In Malaysia, meliternatin (3,5-dimethoxy-32,42,6,7-bismethylendioxyflavone) and six other polyoxygenated flavones (from the plant *Melicope subunifoliolata* were reported as effective insecticides [49].

Some other constituents of plant extracts were suggested to be responsible for the insecticidal activity of those extracts including heptacosane and hexacosane (from the plant *Bauhinia scandens* var. *horsfieldii*) [41], (-)-rocaglamide (from the plant *Aglaia odoratissima*) because (-)-rocaglamide could hold a similar effective antifeedant against the larvae of *Peridroma saucia* [27]. On the other hand, β-citronellal, β-citronellol, linalool and citronellol (identified in the essential oil of *Citrus hystrix*) were reported to be effective insecticide against the larvae of *Spodoptera litura* [38]. Similarly, menthol, limonene, isomenthone, cyclohexanone, 5-methyl-2-(-,ethyl-ethyl)-, isomenthol acetate and cineole (identified in the essential oils of *Mentha piperita* L) were reported to exert a larvicidal activity against the rice weevil (*Sitophilus oryzae*) and the rice moth (*Corcyra cephalonica*) [15]. Likewise, the insecticidal activity of the essential oils of *Piper nigrum* against the second instar of the larvae of *Spodoptera litura* was related to the active constituents in the plant extract including limonene, β-pinene and linalool [13]. Furthermore, the efficacy of the microformulated emulsion of rotenone showed an insecticidal activity against the early third instar larvae of diamondback moth (*Plutella xylostella*) [64].

Conclusion

Several extracts of plants from Southeast Asia were investigated for their insecticidal and repellant activities. However, *Azadiracha indica* (neem) and *Piper* species were highly investigated for their insecticidal and repellant activities than other plants which could be promising to have insecticidal and repellant activities including *Aloe vera* and *Agalia* species. In addition, investigations should be expanded to include plants which are reported to exert insecticidal and repellant activities elsewhere. Nonetheless, most of the conducted studies have been still in the primarily stage of investigations and lack a focus on the insecticidal and repellant spectrum. The identification of the active constituents which are responsible for the insecticidal and repellant activity is an essential study for future endeavor for this application.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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