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Research Article

Assessing the efficacy of soapberry (*Sapindus rarak*) crude extract for controlling giant African land snail (*Lissachatina fulica*)

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Abstract

The giant African land snail (*Lissachatina fulica*) is a major pest that damages agricultural products and the environment, along with raising public health concerns. Although various methods have been applied to control these invasive snails, they have various limitations. The use of plant extracts is an alternative control method that is environmentally friendly and can reduce the use of harmful chemicals. This study was established to evaluate the molluscicidal effects of soapberry crude extract and to develop a molluscicide from it to control the giant African land snail. The soapberry (*Sapindus rarak*) crude extract exerted molluscicidal effects against *L. fulica* within 4 h. Soapberry concentration of 30% caused snail mortality of nearly 90% in 72 h. This plant extract exerted potential repellent and molluscicidal effects in the laboratory and semi-field experiments, while having no observable toxic effects on the vegetable *Brassica rapa* L. Thus, *S. rarak* crude extract at this concentration is suitable for snail control in vegetable plots.

Key words: plant extract, snail control, saponin, molluscicide

Introduction

The giant African land snail, *Lissachatina fulica* (Bowdich, 1822) (formerly known as *Achatina fulica*), is one of the large land snails included in 100 of the world's worst invasive alien species (Lowe et al. 2000). This snail has adverse effects on agriculture, the environment, and public health. It can feed on over 500 different plants including crops (Budha and Naggs 2008). Many studies have demonstrated that *L. fulica* is the destructive pest affecting agriculture in subtropical and tropical areas (Albuquerque et al.

2008; Budha and Naggs 2008; Vijayan et al. 2020). *Lissachatina fulica* is also important medically because it acts as an intermediate host of the nematode *Angiostrongylus cantonensis* or rat lungworm, which can cause angiostrongyliasis in humans. In Thailand, the rainy season is the most common time of year for the emergence of eosinophilic meningitis in endemic areas. This may be associated with the abundance of intermediate snail hosts, including *L. fulica.* (Aekphachaisawat et al. 2018). A study by Vitta et al. (2011) showed that the prevalence of *A. cantonensis* in giant African land snails in Phitsanulok Province, Thailand, was 12.38%. The giant African land snail is the most damaging land snail pest because of its impacts on the economy via damage to agricultural products and associated environmental problems, as well as being a cause of eosinophilic meningitis. There is thus a need for a method to control this snail.

Many methods have been applied to control invasive snails, including mechanical, physical, chemical, and biological strategies. Chemical control is currently a popular method used to control invasive snails. Such chemicals commonly include metaldehyde or methiocarb, aldehyde, iron phosphate, copper sulfate, and pentahydrate. This method is popular with farmers because it is practical and easy to use. However, these chemicals are toxic to beneficial invertebrates such as earthworms and carabid beetles, and harmful to non-target organisms, including humans, and the environment in general (Homeida and Cooke 1982; Purvis and Bannon 1992; Raut and Barker 2002). As an alternative to chemical control, methods of biological control of giant African land snails have been developed using the gastropod parasitic nematodes *Phasmarhabditis hermaphrodita* mixed with water, which are sprayed on the soil. However, the host range of *P. hermaphrodita* is not entirely understood and there are differences in resistance or susceptibility depending on the gastropod species, size, and age, including the ability of nematodes to encase and trap the shells of snails (Rae et al. 2006, 2009). *Lissachatina fulica* was shown to be highly resistant to *P. hermaphrodita* in a susceptibility study by Williams and Rae (2015). Native species extinction is the crucial negative impact resulting from using biological control. The use of predator snails, *Euglandina rosea* and snail-eating flatworm *Platydemus manokwari* for *L. fulica* control caused a decline of native snails (Clarke et al. 1984; Sugiura and Yamaura 2009; Christensen et al. 2021; Gerlach et al. 2021). The use of plant extracts to control invasive pests such as slugs, golden apple snails, and giant African land snails is an alternative method to reduce plant loss. It can reduce the input of chemical molluscicides and is safe for consumers and the environment. Therefore, in recent years, an increasing number of studies of plant extracts to control invasive snails have been performed in many countries, including Thailand. According to these previous studies, plants in the species *Camellia sinensis*, *C. oleifera*, *Sapindus rarak*, *Derris elliptica*, *Acacia concinna*, *Piper betle*, *P. longum*, and *Agave americana*

containing high saponin concentrations exert molluscicidal effects and can be used to control invasive snails (Parmar et al. 1997, 1998; Kitagawa et al. 1998; Mimaki et al. 1999; Lu et al. 2000; Navickiene et al. 2000; Facundo et al. 2005; Yokosuka and Mimaki 2009; Todkar et al. 2010; Chen et al. 2012; Kijprayoon et al. 2014). Saponin extract from *Pulsatilla chinensis* was also shown to be effective for controlling *Oncomelania hupensis* (Chen et al. 2012). Regarding the use of soapberry extract on invasive snails, the pericarp of *Sapindus rarak* showed molluscicidal activity on aquatic snails (Hamburger et al. 1992). Moreover, *S. mukorossi* extract was shown to be effective against vector snails such as *Lymnaea acuminata* and golden apple snails (Huang et al. 2003; Upadhyay and Singh 2011). Although many studies on the use of soapberry crude extract to control invasive snails have been performed, few have focused on the land snail *L. fulica* and there has been limited study on the toxicity of plant extracts to crops. Furthermore, *S.rarak* crude extract were not developed into molluscicide products. Against this background, this study aimed to assess the efficacy of *S. rarak* for controlling giant African snails by evaluating its molluscicidal and feeding deterrent effects, along with its phytotoxicity, including in a trial in a semi-field environment.

Materials and methods

Snail preparation

Adult *L. fulica* were collected from forests and agriculture fields in Roi Et Province, northeastern Thailand, and Chonburi Province, eastern Thailand, during the rainy season (32–36 °C). Snails were carried back to the laboratory within 7 h and acclimated to room temperature (28–32 °C) for a week in a plastic box covered by a nylon net. They were fed daily with organic leaves of ivy gourd (*Coccinia grandis* L.), papaya (*Carica papaya* L.), and cabbage (*Brassica oleracea* L.). The snail rearing box was covered with a net on the top, supplemented with 5 cm of soil, and humidified using a water spray. Dead or moribund snails were discarded. Only active snails were selected for the studies by observing their movement of the foot muscle, eye stalks, and tentacles, and the ability of the foot muscle to attach to a surface (Ciomperlik et al. 2013). The use of animals in this study was approved by the Animal Care and Use Committee, Faculty of Tropical Medicine, Mahidol University (approval number FTM-ACUC 014/2018).

Plant collection, identification, and extraction

The fruits of soapberry (*Sapindus rarak*) (Figure 1) were collected from Kaeng Hang Maeo district, Chanthaburi Province, eastern Thailand. The plants were identified by their morphological characters (Welzen 1997). A voucher specimen was deposited at the Department of Public Health, Sirindhon College of Public Health, Chonburi, Thailand.

Figure 1. The fruit of *Sapindus rarak.* Photo by Lueangkaew Koysap.

For extraction, 200 g of *S. rarak* fruits were weighed, cut into small pieces, and macerated with 350 ml of 95% ethanol at room temperature for 48 h. This mixture was filtered and concentrated by evaporation in a rotary evaporator. The final yield of 37 g of crude extract was stored in a refrigerator and dissolved in 40 ml of 95% ethanol before use.

Quantification of phytochemical constituents

The major saponins of *S. rarak* are glycosides of hederagenin (Hamburger et al. 1992). Saponin content of *S. rarak* crude extract was determined for hederagenin using high-performance liquid chromatography (HPLC) at the Bureau of Cosmetics and Hazardous Substances, Department of Medical Sciences, Ministry of Public Health, Thailand. Separation was carried out using a C18 column (BEH C18 2.1 × 100 mm i.d., 1.7 µm). Isocratic elution was performed using acetonitrile: 0.2% acetic acid (65:35, v/v) as a mobile phase. The flow rate was set at 0.4 ml/min. The injection volume was 2 µL. Detection was set at UV 210 nm. Total run time was 8 min. The quantification of hederagenin from crude extract was repeated after 1 month of storage at room temperature (28–34 °C) and daytime light intensity of 260–400 Lux, to test the stability of the active ingredient.

Molluscicidal effect

The molluscicidal effect of *S. rarak* crude extract was analyzed in accordance with WHO guidelines (World Health Organization 1965). Each treatment included 10 individuals (one snail per glass beaker) and was conducted for three replications. Each snail was directly exposed to 0.2 ml of crude extract at the foot muscle using pipette for the treatment group. The crude

extract was prepared by dilution of stock solution with distilled water to obtain concentrations of 50%, 30%, 25%, 20%, and 15%. For the control group, distilled water was used.

Mortality and abnormal signs of *L. fulica* were observed according to the method of Ciomperlik et al. (2013) and Upadhyay and Singh (2011) every 24 h for 72 h. The mortality of snails was determined by holding each snail and stimulating the foot muscle with a dissection probe for 15 s. The lack of a motor response was considered evidence of mortality.

Feeding tests

The *S. rarak* crude extracts at selected concentrations were studied for their deterrent effect against feeding by *L. fulica* to assess whether the crude extract can protect crops from being eaten by *L. fulica*. We applied the method described in the protocols of Smith et al. (2013) and Jeong et al. (2012). The decided numbers of individuals and replications differed from the original protocols because of the availability of *L. fulica* during the study period. The snails were acclimated in the laboratory for 1 week before starting the experiment. The analysis was divided into choice and no-choice feeding tests. The feeding activity of the snails was compared between *S. rarak* crude extract-treated and untreated leaves. Treated leaves were prepared by spraying 50 g of pak choi (*Brassica rapa* L.) with 5 ml of 30% soapberry crude extract, while untreated leaves were sprayed with water. The concentration of 30% was selected according to the result of the molluscicidal effect. Water was supplied in the rearing box throughout the experiment using moistened cotton wicks. For choice feeding tests, 10 snails were released into a 16 L plastic box. The rearing box was separated into areas for placing treated and untreated leaves, which were freely accessible to the snails. For the no-choice feeding test, 10 snails were kept in each of two separated rearing boxes. In one box, feeding with treated leaves was performed, while the other, untreated leaves were provided. The feeding behavior and quantity of feeding were observed daily for 3 days. Fresh treated or untreated leaves were replaced every 24 h.

Phytotoxicity

The effect of *S. rarak* crude extract was assessed on pak choi (*B. rapa*) to confirm its safety for use on farms cultivating vegetables. The test was adapted from Organization for Economic Co-operation and Development guideline 227 (OECD 2006). *B. rapa* were grown from seeds in a 1 × 1 m vegetable plot located in an organic farm using 350 seeds per plot. Four plots were prepared in identical environmental conditions with daily watering. Different concentrations of *S. rarak* crude extract were prepared by diluting the stock solution with distilled water. After 15 days, the two- to four-true-leaf-stage plants in each plot were sprayed with 30%, 60%, and

100% crude extract and distilled water as a control at an application rate of 20 ml/m^2. The plants were observed for damage and mortality daily for 14 days. A survival rate of at least 90% was acceptable for the control group. Plant survival was measured and compared with that in the control group daily for 14 days.

Semi-field trial

The molluscicidal effect of soapberry crude extract was assessed under field conditions. The method was adapted from Ciomperlik et al. (2013). Two sets of 1 × 1 m vegetable plots were prepared and fenced off using roof tile to get 0.5 m height in the organic farm at Narerk subdistrict, Phanat Nikhom district, Chonburi Province. *Brassica rapa* was grown from seeds for 3 weeks and adjusted to 180 sprouts in each plot. The air temperature was 32–36 °C. There was no precipitation during that period. *S. rarak* crude extracts at LC_{90} in laboratory molluscicidal assays were prepared by the dilution of stock solution with distilled water and sprayed in the vegetable plots at an application rate of 20 ml/m^2. The control plot was sprayed with distilled water in the same way. Ten active adult snails were released into each vegetable plot. The mortality and snail behaviors, such as feeding behavior, movement, and mucus secretionwere observed daily for 3 days.

Data analysis

The effects of *S. rarak* crude extract on giant African land snails were analyzed using Probit analysis (SPSS 15.0 software) and expressed as lethal concentration 50% (LC_{50}) and 90% (LC_{90}) with 95% confidence intervals for 24, 48, and 72 h.

Results

Quantification of hederagenin

The ethanolic extract from dried *S. rarak* fruits gave a yield of 18.5% w/w. HPLC analysis showed that the extract had hederagenin content of 0.2% w/w. However, the hederagenin content decreased to 0.13% w/w after storage at room temperature for 1 month.

Molluscicidal effect

After exposure to *S. rarak* crude extract, *L. fulica* slowly retracted their soft bodies into the shell. Some released clear mucus mixed with the extract, which turned brown and overwhelmed their aperture. Foam formation was also observed (Figure 2). The snails shrank markedly, followed by a cessation of movement. They did not respond to stimulation, with the foot muscle becoming hard and death occurring at 4 h. The dose-response relationship for soapberry concentrations and mortality rate of *L. fulica* after exposure to soapberry extract at 24, 48, and 72 h are presented in Figure 3.

Figure 2. *Lissachatina fulica* after exposure to *Sapindus rarak* crude extract. Photo by Lueangkaew Koysap.

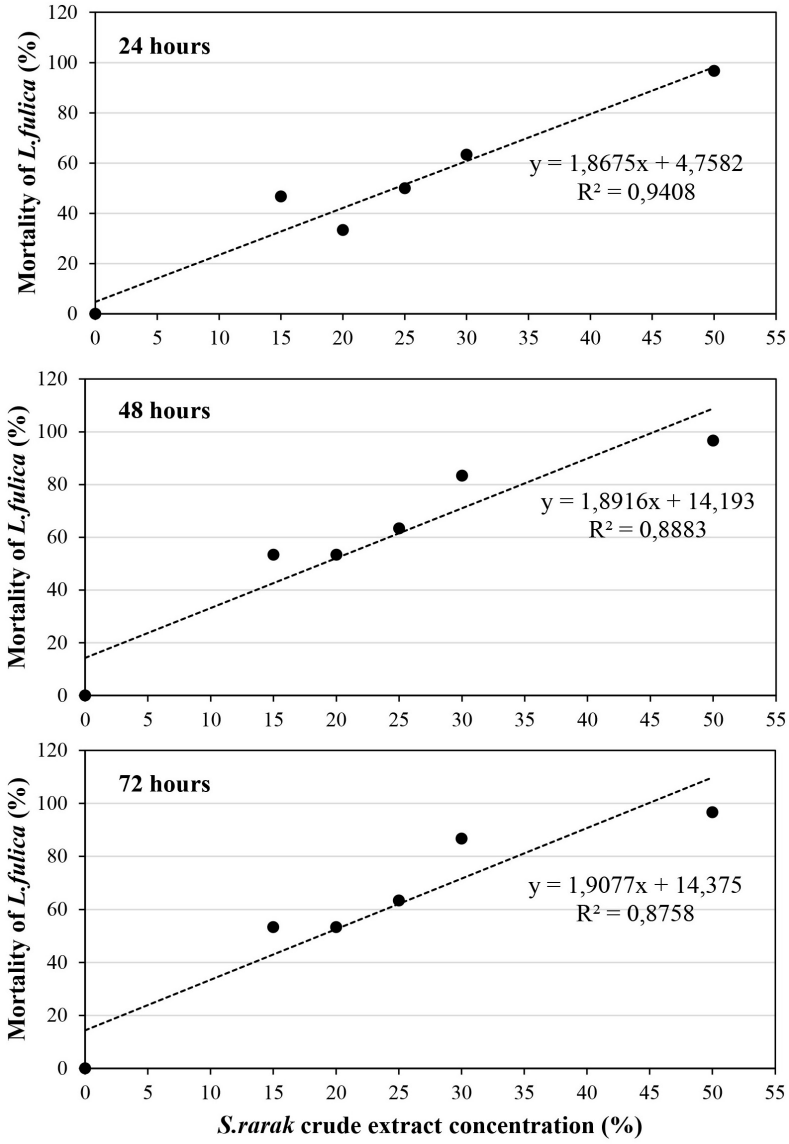

Figure 3. Mortality (%) of *Lissachatina fulica* after exposure to *Sapindus rarak* crude extract. Linear equations (y) of the trendline and R^2 values (coefficient of determination) showing the relationship between the concentration of *S. rarak* crude extract after 24, 48, and 72 hours of exposure.

Table 1. Lethal concentration 50% (LC_{50}) and 90% (LC_{90}) of *Sapindus rarak* crude extract (%).

Exposure period	LC_{50}	95% confidence limit	LC_{90}	95% confidence limit
24 h	23.73	20.57–27.10	42.43	37.14–51.55
48 h	18.88	15.62–21.76	35.67	31.43–42.76
72 h	18.65	15.44–21.47	34.97	30.87–41.80

The mortality rates (%) of *L. fulica* after exposure to soapberry crude extract at various concentrations were observed at 24, 48, and 72 h. The mortality of the snails increased gradually with the increase of *S. rarak* concentration. Most of the snail mortality occurred within 24 h, then slightly increased at 48 h, and became relatively stable until 72 h. Mortality rates of the snails exposed to 15%, 20%, 25%, 30%, and 50% *S. rarak* crude extracts at 72 h were 53.33%, 53.33%, 63.33%, 86.70%, and 96.67%, respectively (Figure 3). The lethal concentration of *S. rarak* that caused 50% and 90% snail mortality (LC_{50} and LC_{90}) decreased from 23.73 and 42.43% at 24 h to 18.65 and 34.97% at 72 h. (Table 1).

Feeding test

After releasing the snails in the rearing box in both choice and no-choice tests, the snails were able to move around the boxes. However, once the snails extended their eyestalks and foot muscle to *S. rarak* crude extract-treated leaves, they slowly retracted their eyestalks, released mucus, withdrew half of their foot muscle into the shell, and stopped moving. After 30 min, they started to extend their foot muscle again and move around the edge of the container while not eating plant sample leaves.

In the choice test, the snails were fed both 30% *S. rarak* crude extract-treated and untreated leaves. No treated leaves were damaged, while all untreated leaves were eaten at 24, 48, and 72 h. Similar to the results in the no-choice test, the treated leaves were not damaged at 72 h. Meanwhile, the snails fed on untreated leaves had normal feeding behavior and were able to eat all of the leaves. Therefore, a *S. rarak* extract concentration of 30% might be a feeding deterrent for *L. fulica*. All of the snails survived until the end of the study.

Phytotoxicity

Crude *S. rarak* extract at a concentration of 30% did not show a phytotoxic effect on *B. rapa.* The survival rate of *B. rapa* was 100% until 14 days in this study. At a concentration of 60%, mild chlorosis of the leaves was observed in 39 of 385 plants (10.2%) at 96 h. However, all plants recovered to normal within 2 weeks of observation, and the survival rate was 100%. The extract concentration of 100% caused 4 of 385 plants to wilt (1.04%) and 77 of 385 plants to exhibit chlorosis (20%) within 72 h. These detrimental effects persisted for 1 week, but most of the plants recovered to normal within 2 weeks. However, 2.6% (10 of 385 plants) mortality of the plants

Table 2. Survival and visible injury of *Brassica rapa* (%) after exposure to *Sapindus rarak* crude extract.

S. rarak concentration	24 h	48 h	72 h	96 h	1 wk	2 wk
Plant survival (%)						
Control	100	100	100	100	100	100
30%	100	100	100	100	100	100
60%	100	100	100	100	100	100
100%	100	100	100	100	100	97.4
Visible injury (%)						
Control	0	0	0	0	0	0
30%	0	0	0	0	0	0
60%	0	0	0	10.20*	10.20*	0
100%	0	0	20.00* 1.04**	20.00* 1.04**	20.00* 1.04**	2.60***

h = hours wk = week (s) *Chlorosis **Wilting *** Mortality.
Each concentration was tested on 385 plants.

Figure 4. Semi-field experiment. The control vegetable plot (left) at 72 hours showed some of *Brassica rapa* were eaten by the snails. The snails after spraying *Sapindus rarak* crude extract for 30 minutes (right). Photo by Lueangkaew Koysap.

was observed at 2 weeks (Table 2). The results indicated that 30% *S. rarak* crude extract was safe for *B. rapa*; hence, this concentration was selected for testing in a semi-field experiment.

Semi-field experiment

After a single spray of 30% *S. rarak* crude extract, the snails were released into the plot and observed for 72 h. In the first 30 min, the snails were able to move around the plot, but then became still, retracted their foot muscle and eyestalks, and some released mucus (Figure 4). On the second day, all snails in the *S. rarak* crude extract group were inactive in the plots and stayed still until 36 h. After watering the plot, all snails extended their foot muscle and eyestalks, and then moved to the edge of the plot, hanging on the highest point of the barriers, and attempted to escape from the vegetable pod. From the results, 50% mortality of the snails from the crude extract group was observed at 48 h. There was no additional mortality until 72 h. The surviving snails from the 30% *S. rarak* crude extract group were inactive until 72 h (Table 3). The snails from the control group did not ingest the

Table 3. Semi-field evaluation of soapberry crude extract against *Lissachatina fulica* in *Brassica rapa* plot.

Group	Mortality of *L. fulica* (%)				Damaged leaves (%)			
	N	24 h	48 h	72 h	N	24 h	48 h	72 h
30% *S. rarak* crude extract	10	0	50	50	180	0	0	0
Control	10	0	0	0	180	0	0	16.7

h = hours.

plants for 2 days, and then started to eat and caused damage to 16.7% of plants at 72 h of observation (Figure 4). The application of *S. rarak* crude extract at a concentration of 30% to a *B. rapa* plot showed its potential effects against *L. fulica* on vegetable farms.

Discussion

In this study, *S. rarak* crude extract at a concentration of 30% caused 63.33% mortality of *L. fulica* within 24 h, which increased to 86.67% at 72 h. However, this formulation achieved only 50% mortality at 72 h in a semi-field environment. The extract was directly applied to snails in the laboratory study, while it was sprayed on the plants in the semi-field experiment, thus reducing snail exposure. Castillo-Ruiz et al. (2018) also found that the molluscicidal activity of quinoa (*Chenopodium quinoa*) against *Pomacea maculata* decreased in field assays compared with the level in laboratory assays and recommended extending the exposure time to obtain a better effect. The repeated spraying of *S. rarak* crude extract at appropriate intervals may help increase snail mortality in the field, but the phytotoxicity should be concerned. However, the feeding deterrence was sufficient to reduce crop damage from *L. fulica.*

Sapindus rarak belongs to the family Sapindaceae and is distributed across Africa, South Asia, and Southeast Asia. It is an indigenous detergent plant of Thailand that acts as a source of natural saponins (Wisetkomolmat et al. 2019). *Sapindus rarak* extract is commonly used as a supplement to traditional herbal shampoo. However, other potential effects, such as acting as a defaunating agent of rumen fermentation (Wina et al. 2005, 2006) and preventing obesity (Asao et al. 2009), were also discovered. Phytochemical study revealed that four O-acetylglycoside saponins are significant components of *S. rarak*. These saponins showed molluscicidal activity in aquatic snails. The pattern of chemical compound extracts from the pericarps of *S. rarak* was similar to that of acyclic sesquiterpene glycosides isolated from *S. mukurossi* and *S. delavayi*; these plants also exert molluscicidal activity on snail pests (Hamburger et al. 1992). Although the molluscicidal effects of soapberry crude extract have been studied previously, most studies focused on aquatic snails. Only a few studies on land snails such as *L. fulica* have been reported (Dyatmiko et al. 1983).

Therefore, our study confirmed the molluscicidal activity of *S. rarak* in land snails. Furthermore, *S. rarak* crude extract showed two crucial effects

of a potential molluscicide: mortality and feeding deterrence. The observable formation of foam and excess mucus production after direct exposure to *S. rarak* crude extract were caused by the detergent effect of saponin on the soft body membrane of *L. fulica* (Francis et al. 2002). The mucus may be released to prevent direct contact between the irritant and the snail's epithelium, acting as a stress response. However, water content, ions, and carbohydrates lost with the extruded mucus can also cause dehydration and energy loss, leading to mortality (Triebskorn et al. 1998). A method involving direct exposure to silica particles had the same effect on land snails and slugs, with mortality being due to the loss of body fluid (Selvi et al. 2015).

The anti-feeding activity of *S. rarak* crude extract may be due to the bitterness associated with saponins (Güçlü-Üstündağ and Mazza 2007). This property has an advantage in pest management in that it can reduce the damage to crops (Koul 2008), especially when the direct exposure to snails is limited. The oral exposure of saponin-rich plant extracts from *Camellia oleifera*, *Gleditsia amorphoides*, and *Quillaja saponaria* against the slug *Deroceras reticulatum* showed lethal toxicity and anti-feeding activity (González-Cruz and Martín 2013). The anti-feeding effect of saponin was also reported in insects (Chaieb 2010). While the natural saponin from *S. mukurossi* was suggested as an environmentally friendly surfactant compared with a synthetic one (Muntaha and Khan 2015), the use of saponin-rich plant extracts should be cautioned that their toxicity depends on their origins and sensitivity of non-target organisms (Jiang et al. 2018). Further studies on the effects of *S. rarak* crude extract on non-target species are needed to expand its other uses, while also confirming its availability for an environmentally friendly alternative method of snail control. Adomaitis and Skujienė (2020) noted that the use of *Quillaja saponaria* bark extract for slug control affected non-targeted white worms (*Enchytraeus albidus*), which may limit the use of this extract. Moreover, a pure fraction of saponin from *S. mukorossi* showed herbicidal effects against broadleaf weeds in an experimental carrot field (Dai et al. 2021). Our study observed that the phytotoxicity of *S. rarak* crude extract was dose-dependent. The recommended 30% crude extract concentration appeared to be safe for the tested vegetable species, *B. rapa*, in terms of mortality and visible injury. However, phytotoxic studies of the extract should be expanded to various plant species to ensure its safety for use on different susceptible species.

From the molluscicidal effect study, the LC_{50} and LC_{90} of *S. rarak* crude extract were higher than previous reports that used crude powder of dried pericarp of *S. mukorossi* fruit against freshwater snail, *Pomacea canaliculata* (Huang et al. 2003) and *Lymnaea acuminata* (Upadhyay and Singh 2011). In this study, the ethanolic extract yield from the fruits of the soapberry was 18.5% and HPLC analysis showed hederagenin content of

0.2%, which is less than previous study. Asao et al. (2009) reported a water extract yield of 25.6% and a methanolic extract yield of 40.7% from the dried pericarps collected in Thailand and HPLC analysis showed hederagenin 0.34%. Morikawa et al. (2009) showed the methanolic extract of the pericarps of *S. rarak* 67.5% from the dried pericarps, and HPLC analysis showed total hederagenin 0.72%. Hamburger et al. (1992) showed hederagenin content in the pericarps of *S. rarak* of 7.5%, with average extraction yield of 16.5%. In this study, we used whole soapberry fruits, which contained both seeds and pericarps; this might have caused the different hederagenin concentrations. Saponin content is also affected by genetic origin, the part of the plant studied, and environmental and agronomic factors associated with the plant's growth (Güçlü-Üstündağ and Mazza 2007). We found a decrease of hederagenin in *S. rarak* crude extract after 1 month of storage at room temperature, which indicated that its stability could be an issue. Our study used crude extract, not the purified saponin fraction; therefore, a link between the specific compound and bioactivity on snail control was not established. In a previous study by Huang et al. (2003), seven fractions of *S. mukorossi* pericarp methanol extract showed molluscicidal effects. The authors suggested developing a molluscicide not only using pure saponin but also from the crude extract.

In conclusion, *S. rarak* ethanol crude extract at 30% is a potential molluscicide against *L. fulica*, especially in small-scale organic farming of *B. rapa*. *Sapindus rarak* crude extract could be used by directly exposing snails to it, resulting in mortality. In addition, spraying the extract on crops could prevent them from being damaged by the snails. Further studies on technologies for extraction to increase the efficiency of active substances should improve the quality of *S. rarak* extract for application in snail control. Moreover, improved stability of the extract is required for further product development.

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Authors' contribution

LK, YL research conceptualization; LK, JR, SA, SK, SW, UT, YL sample design and methodology; LK, YC, SK, SM, SW investigation and data collection; LK, SK, SW, YL data analysis and interpretation; YL, UT, SA ethics approval; ZL funding provision; LK writing – original draft; JR, SA, SK, SW, UT, YL, ZL writing – review and editing.

Ethics and permits

The animal used in this study was approved by the Animal care and use committee, Faculty of Tropical Medicine, Mahidol University (approved number FTM-ACUC 014/2018)

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