Comparative Study on Allelopathic Potential of Medicinal Plants Against the Growth of Cress and Barnyard Grass

Sutjaritpan BOONMEE1,2 and Hisashi KATO-NOGUCHI1

1 Department of Applied Biological Science, Faculty of Agriculture, Kagawa University, 2393 Ikenobe, Miki, Kagawa 761-0795, Japan
2 The United Graduate School of Agricultural Sciences, Ehime University, 3-5-7 Tarumi, Matsuyama, Ehime 790-8566, Japan

(Received January 22, 2019; Accepted April 19, 2019)

Medicinal plants are potential sources of secondary metabolites which may possess allelopathic properties. Hence, we investigated the allelopathic potential of 12 Thai medicinal plants against the growth of cress and barnyard grass. The 12 medicinal plant extracts showed a significant inhibition on the growth of those test plants. The inhibitory potentials depended on the extract concentration and test plant species. Comparing the average growth inhibition, the extracts from Crataeva adansonii strongly inhibited the cress shoots and roots (96.0 and 95.6%), followed by Phlogacanthus pulcherrimus (93.1 and 93.4%), and Cuscuta chinensis (92.3 and 91.5%). Meanwhile, the barnyard grass shoots and roots were strongly inhibited by the extracts of P. pulcherrimus (88.2 and 97.6%), C. chinensis (73.7 and 82.3%), and Acanthopanax trifoliatus (73.0 and 94.3%). However, P. pulcherrimus extracts had a high allelopathic potential against both test plants, suggesting that P. pulcherrimus may be a potential candidate for purification of allelochemicals.

Keywords: allelopathic potential, alternative weed management, inhibitory effect, Phlogacanthus pulcherrimus, secondary metabolites

INTRODUCTION

In conventional agriculture, the use of synthesis herbicides is still recognized as an effective tool to eliminate weeds and to promote the highest possible yield of crops (Norsworthy et al., 2012; Kniss, 2017). On the other hand, the overuse of synthetic herbicides negatively affects both the environment and human health, and increases the number of herbicide-resistant weeds (Aktor et al., 2009; Staley et al., 2015). Also, increasing consumer awareness of herbicide residues in production practices leads to increased demand for organic products or safer foods (McErlich and Boydston, 2013; Tal, 2018). To overcome these problems, reducing the reliance on synthetic herbicides and shifting to sustainable agriculture is needed. Organic farming is a feasible alternative agricultural practice that relies on an integrated natural-based system (Gomiero et al., 2011; IFOAM EU Group, 2016). In this direction, using natural plant products and allelopathy for weed management is gaining attention (Singh et al., 2003). Additionally, using natural substances including plant extracts is considered safe and acceptable in organic farming (Brandt, 2007; Verhoog et al., 2007; Jespersen et al., 2017).

Allelopathy is a biological phenomenon in which plants release secondary metabolites (allelochemicals) that inhibit or stimulate the growth, development, and reproduction of other organisms in the environment (Rice, 1984; Einhellig, 1995). Such secondary metabolites or natural compounds could be considered as a possible alternative strategy for weed management (Bhadoria, 2010; Tesio and Ferrero, 2010). It is generally known that medicinal plants synthesize and accumulate a large amount of natural bioactive compounds, which provide a vital role in many biological activities (Silva and Fernandes Júnior, 2010; Yang et al., 2016). Numerous medicinal plants have been studied for potential allelopathic properties. Fujii et al. (1991) surveyed Japanese medicinal plants to determine their allelopathic properties. They also conducted further screening of 239 medicinal plant species for their allelopathic activity (Fujii et al., 2003). Many natural active compounds have also been isolated from other medicinal plants and reported as allelochemicals (Lin et al., 2004; Pukclai et al., 2010; Kato-Noguchi et al., 2014; Suwitchayanon et al., 2017a; 2017b; Boonmee et al., 2018a; 2018b).

Thailand is located in the biologically complex Asia Pacific region. This vast area has diverse eco-climates and physiography, resulting in wide varieties of plant species as well as medicinal plant varieties that may have the potential to provide natural active substances (Arora, 2014; Hughes, 2017). Hence, screening of medicinal plants with allelopathic properties is the first step to investigate the potentiality of the plant to control weeds. This study, therefore, aimed to evaluate the allelopathic potential of aqueous methanol extracts from 12 Thai medicinal plants against the growth of representative test plants (broad- and narrow-leaved), for further isolation and identification of allelopathic substances.

Corresponding author : Hisashi Kato-Noguchi, fax: +81-87-891-3086, e-mail : hisashi@ag.kagawa-u.ac.jp
MATERIALS AND METHODS

Plant materials
Mature leaves of 12 medicinal plants (Table 1) were randomly collected in the same growth area from Chiang Rai Province, Thailand (N19°52′52.132 and E100°0′48.934), during April–May 2016. The plant materials were washed in tap water to remove tiny particles, dried in the shade to completely dry (till constant weight), ground to a fine uniform texture, and kept in vacuum-sealed plastic packages at 4°C until extraction. Cress (Lepidium sativum L.) and barnyard grass (Echinochloa crus-galli (L.) P. Beauv) were selected as representative of broad- and narrow-leaved test plant species, respectively, to determine the biological activity. Cress seeds were purchased from Nakahara Seed Co., Ltd., November 2017. Barnyard grass seeds were collected from the University Farm, Faculty of Agriculture, Kagawa University, Japan, collected on August 2016.

Preparation of extracts
Leaf powder (20 g) of each plant material was separately extracted with 70% (v/v) aqueous methanol (100 mL) by shaking at 200 rpm for 30 minutes (repeated 3 times) at 25°C. The extracts were filtered through a sheet of No. 2 filter paper (Toyo Roshi Ltd., Japan), and the residues were extracted again with an equal volume of cold methanol (twice) and filtered. The filtrates of each medicinal plant extract were vacuum evaporated until dryness.

Biological activity
A crude extract of each plant material was dissolved in 40 mL of cold methanol. An aliquot of the extracts at final concentrations of 10, 30, 100, and 300 mg DW equivalent extract mL⁻¹ was added to a sheet of No. 2 filter paper in a 28 mm Petri dish. The solvent was evaporated in a laminar flow cabinet. The filter paper was moistened with 0.6 mL of 0.05% (v/v) aqueous solution of Tween 20 (polyoxyethylene sorbitan monolaurate; Nacalai, Kyoto, Japan). Then, 10 seeds of cress and 10 pre-germinated seeds of barnyard grass (soaked in distilled water overnight and allowed to germinate in the dark for 48 hours) were placed on the filter paper in the Petri dish. Seeds or seedlings placed on filter paper moistened with an aqueous solution of Tween 20 without the extract were used as controls. The shoot and root length of the tested plant seedlings were measured after 48 hours incubation in darkness at 25°C. The inhibition percentage was calculated by reference to the length of the control seedlings, using the following equation; Inhibition (%) = \[1 - \frac{\text{Treatment}}{\text{Control}}\times 100\]. The concentrations required for 50% inhibition (defined as IC₅₀) of the test plant species were calculated from the regression equation of the concentration response curves.

Statistical analysis
All experiments were conducted in two independent experiments with three replications (10 seedlings replication⁻¹) for each experiment (n = 60). The data were analyzed by SPSS version 16.0 using one-way ANOVA and subsequent post hoc analysis with Tukey’s tests at P < 0.05. A two-tailed Pearson correlation test was used to analyze the correlation and growth of the test plants. The concentrations required for 50% inhibition of each test plant were analyzed using GraphPad Prism 5.04.

RESULTS

Effect of 12 medicinal plant extracts on the growth of the cress seedlings
All the medicinal plant extracts significantly inhibited the growth of the cress at a concentration of 10 mg DW equivalent extract mL⁻¹ and completely inhibited the growth at higher concentrations (Fig 1A and B). Regression analysis between the extract concentration and seedling growth of the cress showed a negative correlation coefficient (R) in all treatments, with the correlation coefficient values in the range of −0.387 to −0.825 (Table 2). These results indicate that the inhibitory effect of the medicinal plant extracts was concentration dependent.

The inhibitory effects of the extracts were also evaluated in terms of average growth inhibition percentage (AV%) (Table 3). Maximum inhibition was evident with the extracts of C. adansonii at 96.0 and 95.6% inhibition against the cress shoots and roots, respectively. The degree of the growth inhibition percentage was in the order of the extracts of C. adansonii > P. pulcherrimus > C. chinensis. However, the remaining plant extracts also inhibited the cress seedlings at more than 80% compared with

Table 1 List of selected Thai medicinal plants.

| Plant no. | Scientific name                      | Family            |
|----------|--------------------------------------|-------------------|
| MP-1     | Codiaeum variegatum (L.) Blume       | Euphorbiaceae     |
| MP-2     | Acanthopanax trifoliatus (L.) Merrill| Araliaceae        |
| MP-3     | Phlogacanthus pulcherrimus T. Anderson| Acanthaceae       |
| MP-4     | Cuscuta chinensis Lamarck             | Cucurbitaceae     |
| MP-5     | Operculina turpethum (L.) S. Manso    | Convolvulaceae    |
| MP-6     | Gymnura procumbens (Lour.) Merril    | Asteraceae        |
| MP-7     | Polyscias fruticosa (L.) Harms       | Araliaceae        |
| MP-8     | Aspidistra sutepecsis K. Larsen      | Asparagaceae      |
| MP-9     | Polygonum tomentosum Wildenow        | Polygonaceae      |
| MP-10    | Crateva adansonii DC. subsp. trifoliata (Roxb.) Jacobs | Capparaceae |
| MP-11    | Caesalpinia farfaracea (Prain.) Hattink | Fabaceae      |
| MP-12    | Diplazium esculentum (Retz.) Swartz   | Athyriaceae      |
**Table 2** Correlation coefficient (R) between extract concentration of 12 Thai medicinal plants and the seedling growth of cress and barnyard grass.

| Medicinal plant species | Hypocotyl | Root | Shoot | Root |
|-------------------------|-----------|------|-------|------|
| *C. variegatum*         | −0.61**   | −0.92** | −0.82** | −0.65** |
| *A. trifoliatum*        | −0.75**   | −0.86** | −0.63** | −0.58** |
| *P. palucherrimus*      | −0.51*    | −0.59** | −0.45* | −0.62** |
| *C. chinensis*          | −0.45*    | −0.71** | −0.63** | −0.50* |
| *O. turpethum*          | −0.50*    | −0.86** | −0.70** | −0.61** |
| *G. procumbens*         | −0.61**   | −0.84** | −0.74** | −0.65** |
| *P. fruticosus*         | −0.51*    | −0.93** | −0.75** | −0.57** |
| *A. sutopenis*          | −0.76**   | −0.78** | −0.58** | −0.83** |
| *P. tomentosum*         | −0.49*    | −0.86** | −0.53** | −0.59** |
| *C. adansonii*          | −0.39     | −0.99** | −0.86** | −0.69** |
| *C. furfuracea*         | −0.49*    | −0.72** | −0.52** | −0.60** |
| *D. esulentum*          | −0.49*    | −0.93** | −0.77** | −0.58** |

Correlation is significant at **P < 0.01 and *P < 0.05 (2-tailed).

Fig. 1 The growth inhibitory effects of 12 Thai medicinal plants on the cress shoots (A), cress roots (B), barnyard grass shoots (C), and barnyard grass roots (D). All test plants were treated with 10, 30, 100, and 300 mg DW equivalent extract mL$^{-1}$. Significant differences between control and treatments are represented by asterisks: *P<0.05, **P<0.01, ***P<0.001 (One-way ANOVA, Tukey’s HSD test).
Table 3  Average growth inhibition percentage of aqueous methanol extracts from 12 Thai medicinal plant on the tested seedling growth.

| Medicinal plant species | Average inhibition percentage (%) | Cress | Barnyard grass |
|-------------------------|----------------------------------|-------|---------------|
|                         | Hypocotyl | Root | Shoot | Root |
| C. variegatum           | 79.3d     | 82.5b | 65.6d | 75.4c |
| A. trifoliatum          | 85.3ef    | 81.3b | 73.0bc | 94.3ab |
| P. pulcherrimus         | 93.1abc   | 93.4b  | 88.2a  | 97.6bc |
| C. chinensis            | 92.3abc   | 91.5bc | 73.0b  | 82.3d |
| O. turpethum            | 89.9ed    | 89.5cd | 65.3d  | 81.6d |
| G. procumbens           | 82.1fg    | 85.4dfg | 59.5e  | 76.4e |
| P. fruticosa            | 92.0eabc  | 87.5fcd | 56.4e  | 93.4b |
| A. tabifolium           | 91.7fg    | 88.8ef  | 72.5de | 92.0b |
| P. tomentosum           | 90.8fcd   | 89.6e   | 59.1d  | 95.0ab |
| C. adansonii            | 96.0a     | 95.9a   | 66.1d  | 66.6f |
| C. furfuracea           | 94.7eab   | 89.4abc | 68.3d  | 86.4e |
| D. esculentum           | 88.0fde   | 84.3gh  | 47.8f  | 78.6h |

The bioassay was conducted with four concentrations (10, 30, 100 and 300 mg DW equivalent extract mL\(^{-1}\)) of 12 Thai medicinal plant extracts. The average inhibition percentage was calculated for all concentrations of each plant extract. Data were expressed as Mean from 2 independent experiments with 3 replications of 10 seedlings for each determination (n=60). Means of the treatment with the same superscript letter in each row are not statistically different at P < 0.05 using Duncan.

Fig. 2  The required concentration of aqueous methanol extracts from 12 Thai medicinal plants for 50% growth inhibition (I\(_{50}\) value) of cress (A) and barnyard grass (B). MP-1, Codiaeum variegatum; MP-2, Acanthopanax trifoliatum; MP-3, Phlogacanthus pulcherrimus; MP-4, Cuscuta chinensis; MP-5, Operculina turpethum; MP-6, Gymura procumbens; MP-7, Polyscias fruticosa; MP-8, Aspidistra sutopenensis; MP-9, Polygonum tomentosum; MP-10, Crateva adansonii; MP-11, Caesalpinia furfuracea; and MP-12, Diplazium esculentum.
control.

The \( I_{50} \) values of the extracts against the cress shoots ranged from 1.6 to 11.4 mg DW equivalent extract mL\(^{-1}\), and that against the cress roots was 1.1 to 9.6 mg DW equivalent extract/mL (Fig 2). In addition, the \( I_{50} \) value of the C. adansonii extracts was lower than the other plant extracts, followed by the extracts of P. pulcherrimus and C. chinensis.

Effect of 12 medicinal plant extracts on the growth of the barnyard grass seedlings

The seedling growth of the barnyard grass was also inhibited by the 12 medicinal plant extracts with different inhibition values. The extracts significantly inhibited the seedlings at a concentration greater than 30 mg DW equivalent extract mL\(^{-1}\) (Fig 1C and D). The growth of the barnyard grass had a significant negative correlation with all the extracts and the correlation coefficient (R) values were \(-0.455 \text{ to } -0.988\) (Table 2), indicating that the inhibitory activity increased with an increase in extract concentration.

Considering the average growth inhibition percentage, the extracts of P. pulcherrimus showed the highest inhibition of the shoot (88.2\%) and root (97.6\%) growth of the barnyard grass, followed by A. trifoliatum, A. sutepensis, and C. chinensis. The other plant extracts inhibited the shoot growth of the barnyard grass by 47.8 to 68.3\% and inhibited the root growth by 66.6 to 95.0\% (Table 3).

The \( I_{50} \) values of the 12 medicinal plant extracts against the barnyard grass shoots and roots ranged from 4.7 to 63.2 and 0.8 to 23.1 mg DW equivalent extract mL\(^{-1}\), respectively (Fig 2). The extracts of P. pulcherrimus had the lowest \( I_{50} \) values compared with the other plant extracts.

DISCUSSION

Aqueous methanol extracts obtained from 12 Thai medicinal plants showed inhibitory potential against the seedling growth of cress and barnyard grass, which were selected as representative of broad- and narrow-leaved weeds, respectively. The growth of the two test plants decreased with the increase in extract concentration. The results are similar to the work of Arafat et al. (2015), who found that increasing Salvia moorcroftiana extract concentration reduced the plumule length of Triticum aestivum. In addition, the \( I_{50} \) values of the cress and barnyard grass indicate variation in sensitivity of both test plants to the extracts, suggesting that the inhibitory effects were also species specific. It has also been reported in several studies that differences in susceptibility of plant species to inhibitory substances may be related to the biochemical and physiological composition of each plant species tested (Hodgson and Mackey, 1986; Kobayashi, 2004; Sodaeizadeh et al., 2009). Thus, the growth inhibition of the 12 medicinal plant extracts suggests that all the extracts may possess allelopathic substances.

Considering the average growth inhibition, the extract of C. adansonii, P. pulcherrimus, and C. chinensis strongly inhibited cress growth, and the extract of P. pulcherrimus, C. chinensis, and A. trifoliatum strongly inhibited barnyard grass. The difference in inhibitory effects of each medicinal plant extracts may result from the different concentrations of secondary metabolites among the plant species and/or the (different) chemical composition of the plant extracts (Wu et al., 2009). The results are in agreement with Roy et al. (2012), who reported that the aqueous extracts of four herbal plant species exhibited different inhibitory effects on germination and seedling growth of swamp cabbage (Impoera aquatica) and lady’s finger (Herbic us esculentus). Furthermore, the degree of inhibition was proportional to the concentration of the each extract (Edwin Carley and Watson, 1968). Our results suggest that all the selected medicinal plant inhibited the seedling growth of the test plants, and the degree of inhibition was concentration and species dependent. In particular, P. pulcherrimus strongly inhibited the growth of both test plants (broad- and narrow-leaved species).

Phlogacanthus pulcherrimus is a medicinal plant in the Acanthaceae family and is widely distributed in northern and northeastern Thailand. The fresh leaves of P. pulcherrimus are edible and have been traditionally used as diuretics (Jongrunguangchok et al., 2014). The biological activity of methanolic extract of P. pulcherrimus has been studied to possess antioxidant, anticancer, and cytotoxic activities (Lordkhem et al., 2015; Poeaim et al., 2016). To our knowledge, this study is the first report on the allelopathic potential of P. pulcherrimus. The phytochemical of P. pulcherrimus has also been investigated by Lordkhem et al. (2015), which showed that the plant leaves possess various chemicals, such as carbohydrates, alkaloids, phenolic compounds, coumarins, triterpenes, diterpenes, and sterols. Phenolic compounds, known as major groups of plant allelochemicals, play a major role in allelopathy (John and Sarada, 2012). Therefore, the presence of phenolic compounds in P. pulcherrimus may be responsible for the inhibitory activity. However, further isolation and identification is necessary to confirm which substances are responsible for the inhibitory activity of P. pulcherrimus.

CONCLUSIONS

The present study suggests that the 12 Thai medicinal plant extracts have allelopathic potential and may have inhibitory substances that act as allelochemicals. In particular, P. pulcherrimus has strong inhibitory activity among the medicinal plant extracts and may be a potential candidate for further isolation and identification of allelopathic active substances that could be used for natural weed control.

ACKNOWLEDGEMENTS

We would like to express our sincere gratitude to The Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan for providing financial support to carry out this research. We also thank Professor Dennis Murphy, The United Graduate School of Agriculture Science, Ehime University, Japan for editing the English of
the manuscript.

REFERENCES

Akter, W., Sengupta, D., Chowdhury, A. 2009. Impact of pesticides use in agriculture: Their benefits and hazards. Interdiscip. Toxicol. 2: 1–12.

Arafat, Y., Khalid, S., Lin, W., Fang, C., Sadia, S., Ali, N., Azeem, S. 2015. Allelopathic evaluation of selected plants extract against broad and narrow leaves weeds and their associated crops. Acad. J. Agric. Res. 3: 226–234.

Arora, R. K. 2014. Diversity in underutilized plant species—An Asia-Pacific perspective. Bioversity International, New Delhi, India, pp 203.

Bhadaria, P. B. S. 2010. Allelopathy: A natural way towards weed management. Am. J. Exp. Agric. 1: 7–20.

Boonmee, S., Iwasaki, A., Suenaga, K., Kato-Noguchi, H. 2018a. Evaluation of phytotoxic activity of leaf and stem extracts and identification of a phytotoxic substance from *Caulerpa limosa*. Lamk. Theor. Exp. Plant Phys. 30: 129–139.

Boonmee, S., Iwasaki, A., Suenaga, K., Kato-Noguchi, H. 2018b. Identification of 6,7-dimethoxychromone as a potent allelochemical from *Jatropha podagrica*. Nat. Prod. Commun. 13: 1515–1518.

Brandt, K. 2007. Organic agriculture and food utilization. The International Conference on Organic Agriculture and Food Security. May 3–5, 2007. FAO, Italy.

Edwin Carley, H., Watson, R. D. 1968. Effect of various aqueous plant extracts upon seed germination. Bot. Gaz. 129: 57–62.

Einhellig, F. A. 1995. Allelopathy-current status and future goals. In “Allelopathy: Organisms, Processes, and Applications” (ed. by Inderjit, A., Dakshini, K. M. M., Einhellig, F. A.). American Chemical Society Press, Washington, DC, pp 1–24.

Fujii, Y., Furukawa, M., Hayakawa, Y., Sugahara, K., Shibuya, T. 1991. Survey of Japanese medicinal plants for the detection of allelopathic properties. J. Weed Sci. Tech. 36: 36–42.

Fujii, Y., Parvez, S. S., Parvez, M. M., Ohmae, Y., Iida, O. 2003. Screening of 239 medicinal plant species for allelopathic activity using the sandwich method. Weed Biol. Manag. 3: 233–241.

Gomiero, T., Pimentel, D., Paolotti, M. G. 2011. Environmental impact of different agricultural management practices: conventional vs. organic agriculture. Crit. Rev. Plant Sci. 30: 95–124.

Hodgson, J. G., Mackey, J. M. L. 1986. The ecological specialization of dicotyledonous families within a local flora: Some factors constraining optimisation of seed size and other possible evolutionary significance. New Phytol. 104: 497–515.

Hughes, A. C. 2017. Understanding the drivers of Southeast Asian biodiversity loss. Ecosphere 8: e01624.

International Federation of Organic Agriculture Movements EU Group (IFOAM EU Group). 2016. Plant health care in organic agriculture and food utilization. The European Federation of Organic Agriculture Movements (IFOAM EU Group). 2016. Plant health care in organic farming: Position paper. 5 pp. Available online: https://www.ifoam-eu.org/sites/default/files/ifoameu_policy_position_paper_plant_health_201604.pdf (Accessed 10 October 2018)

Jespersen, L. M., Baggesen, D. L., Fog, E., Halsnæs, K., Hermansen, J. E., Andreasen, L., Strandberg, B., Sørensen, J. T., Halberg, N. 2017. Contribution of organic farming to public goods in Denmark. Org. Agr. 7: 243–266.

John, J., Sarada, S. 2012. Role of phenolics in allelopathic interactions. Jalsal. J. 29: 215–230.

Jongrungruangchok, S., Songsak, T., Wongwirthanakanuk, S. 2014. Evaluation of nutrient and mineral content of the leaves of *Phlogacanthus pulcher* cultivated in Thailand. Bull. Health Sci. Technol. 12: 22–26.

Kato-Noguchi, H., Pukclai, P., Ohno, O., Suenaga, K. 2014. Isolation and identification of a plant growth inhibitor from *Tinospora rubra*. Acta Physiol. Plant. 36: 1621–1626.

Kniss, A. R. 2017. Long-term trends in the intensity and relative toxicity of herbicide use. Nat. Commun. 8: 14865.

Kobayashi, K. 2004. Factors affecting phytotoxic activity of allelochemicals in soil. Weed Biol. Manag. 4: 1–7.

Lin, D., Tsuzuki, E., Sugimoto, Y., Dong, Y., Matsuo, M., Terao, H. 2004. Elementary identification of phenolic allelochemicals from dwarf lilyturf plant (*Cymbopogon japonicus*) and their growth-inhibiting effects for two weeds in paddy rice field. Plant Prod. Sci. 7: 260–265.

Lokdharm, P., Poeain, S., Charoenying, P. 2015. Plant chemical screening, antioxidant and anticanter activities of *Phlogacanthus pulcher* leaves. The 27th Annual Meeting of the Thai Society for Biotechnology and International Conference. November 17–20, 2015. Bangkok, Thailand, p 568–574.

McElrath, A. F., Boydston, R. A. 2013. Current state of weed management in organic and conventional cropping systems. In “Automation: The Future of Weed Control in Crop Systems” (ed. by Young, S. L., Pierce, F. J.). Springer Science+ Business Medis, Dordrecht, p 11–32.

Norsworthy, J. K., Ward, S. M., Shaw, D. R., Llewellyn, R. S., Nichols, R. L., Webster, T. M., Bradley, K. W., Frisvold, G., Powles, S. B., Burgess, N. R., Witt, W. W., Barrett, M. 2012. Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Sci. 60: 31–62.

Poeain, S., Lokdharm, P., Charoenying, P., Laipasu, P. 2016. Evaluation of antioxidant, cytotoxic activities and total phenolic content of leaf extracts from *Phlogacanthus pulcher* rimus. Int. J. Agric. Technol. 12: 1657–1667.

Pukclai, P., Suenaga, K., Kato-Noguchi, H. 2010. Allelopathic potential and chemical composition of *Rhinacanthus nasutus* extracts. Allelopathy J. 26: 207–216.

Rice, E. L. 1984. Allelopathy, 2nd ed. Academic Press, New York.

Roy, B., Sarker, B. C., Ali, M. R., Das, S. R., Sayed, M. A. S. 2012. Seed germination and seedling growth of two vegetable responses in aqueous extract of four herbal plant leaves. J. Environ. Sci. & Nat. Resour. Res. 5: 141–150.

Silva, N. C. C., Fernandes Júnior, A. 2010. Biological properties of medicinal plants: A review of their antimicrobial activity. J. Venom. Anim. Toxins Incl. Trop. Dis. 16: 402–413.

Singh, H. P., Batish, D. R., Kohli, R. K. 2003. Phytotoxic effects of *Parthenium hysterophorus* residues on three Brassica species. Indian J. Weed Sci. 36: 28–30.

Sodeiizadeh, H., Rafieiolhosaini, M., Havlik, J., Damme, P. V. 2009. Allelopathic activity of different plant parts of *Peganum harmala* L. and identification of their growth inhibitors substances. Plant Grow. Res. 59: 227–236.

Staley, Z. R., Harwood, V. J., Rohr, J. R. 2015. A synthesis of the effects of pesticides on microbial persistence in aquatic ecosystems. Crit. Rev. Toxicol. 45: 813–836.

Suwitchayanon, P., Ohno, O., Suenaga, K., Kato-Noguchi, H. 2017a. *N*-Octanoyl tyramine, a phytotoxic compound in the roots of *Cymbopogon nardus*. Acta Physiol. Plant. 39: 123.

Suwitchayanon, P., Suenaga, K., Iwasaki, A., Kato-Noguchi, H. 2017b. Myrislignan, a growth inhibitor from the roots of *Citrinella gr. Em*. Nat. Prod. Commun. 12: 1077–1078.

Tal, A. 2018. Making conventional agriculture environmentally friendly: moving beyond the glorification of organic agriculture and the demonization of conventional agriculture. Sustain. 10: 1078

Tesio, F., Ferrero, A. 2010. Allelopathy, a chance for sustainable weed management. Int. J. Sust. Dev. World. 17: 377–389.

Verhoog, H., Buuren, E. T. L. V., Matze, M., Baars, T. 2007.
The value of ‘naturalness’ in organic agriculture. NJAS-Wagen. J. Life Sc. 54: 333–345.
Wu, A. P., Yu, H., Gao, S. Q., Huang, Z. Y., He, W. M., Miao, S. L., Dong, M. 2009. Differential belowground allelopathic effects of leaf and root of Mikania micrantha. Trees 23: 11–17.
Yang, L., Yang, C., Li, C., Zhao, Q., Liu, L., Fang, X., Chen, X. Y. 2016. Recent advances in biosynthesis of bioactive compounds in traditional Chinese medicinal plants. Sci. Bull. 61: 3–17.
