PLANT SCIENCE

Plant growth inhibitory activity of medicinal plant *Hyptis suaveolens*: could allelopathy be a cause?

A. K. M. Mominul Islam\(^1,2*\) and Hisashi Kato-Noguchi\(^1\)

\(^1\)Department of Applied Biological Science, Faculty of Agriculture, Kagawa University, Miki, Kagawa 761-0795, Japan
\(^2\)Department of Agronomy, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh

Abstract

The present study was conducted to explore the allelopathy of *Hyptis suaveolens* Poit, an important medicinal plant of Lamiaceae family. The aqueous methanol extracts of this plant at four different concentrations (3, 10, 30 and 100 mg dry weight [DW] equivalent extract/mL), were examined on the seedling growth of eight test plant species, cress (*Lepidium sativum* L.), lettuce (*Lactuca sativa* L.), alfalfa (*Medicago sativa* L.), rapeseed (*Brassica napus* L.), timothy (*Phleum pratense* L.), crabgrass (*Digitaria sanguinalis* L. scop.), barnyardgrass (*Echinochloa crus-galli* L.) and Italian ryegrass (*Lolium multiflorum* Lam.), and on the germination of cress and Italian ryegrass. The germination of cress, Italian ryegrass and the growth of all eight test species were significantly inhibited by the *H. suaveolens* plant extracts at a concentration greater than 3, 30 and 10 mg DW equivalent extract/mL, respectively. The inhibitory activity of the extracts was concentration dependent. The concentrations required for 50% inhibition (defined as \(I_{50}\)) of the hypocotyl/coleoptile and root growth of the eight test plant species range from 9.3–79.3 and 4.9–29.5 mg DW equivalent extract/mL, respectively. The hypocotyl growth of lettuce and the root growth of crabgrass were most sensitive to the extract, whereas coleoptile growth of barnyardgrass and the root growth of alfalfa were the least sensitive. The inhibitory activities of the *H. suaveolens* on the germination and growth of the test plant species suggest that the plant has allelopathic potentiality and may possess allelochemicals. These allelochemicals might be responsible for the restricted growth of other plant species near their colony in natural ecosystems. However, isolation and identification of these allelochemicals from *H. suaveolens* plant extracts could serve as the lead for new natural herbicides development for sustainable weed management strategies.

Key words: Allelochemicals, Weed management, Sustainable agriculture, Lamiaceae, Natural herbicide

Introduction

The initial use of synthetic herbicides to control weeds in the crop fields superficially increased the crop production by reducing the weed infestation. Eventually the excessive use of synthetic herbicide in the crop fields may obviously lead to a tremendous environmental hazards resulting in degradation of agricultural land by abolishing soil-biota (Pell et al., 1998); ground water contamination (Aktar et al., 2009); reduction of fisheries (Khan and Law, 2005); development of herbicide resistant weeds (Vyvyan, 2002); destruction of beneficial predators of pests and thereby increased the virulence of many species of agricultural pests (Wilson and Tisdell, 2001). To avoid the hurtful effects of synthetic herbicide, research on novel natural plant products have moved from the fringe to the mainstream for the development of ecologically acceptable, environment friendly, cost-effective and relatively safe natural herbicides.

Allelopathy of medicinal plants could play a vital role in identification of new allelochemicals and could accelerate the process of new natural herbicides development. Currently, many researches around the world show their keen interest on medicinal plants for searching new novel compounds and reported that medicinal plants have growth inhibitory effects on different noxious weed species and have the potentiality to use them in the crop fields either directly or as a natural herbicides (Lin et al., 2003, 2004; Han et
al., 2008; Sodaeizadeh et al., 2009; Li et al., 2009). Moreover, it was reported that screening of allelopathic plant from medicinal plants species is easier than other plants (Fujii et al., 2003) possibly due to their existed certain metabolic compounds which was used for curing many diseases of both animal and human being. On the other hand, there are about 400,000 secondary metabolites in plants with allelopathic activities (Swain, 1977), of which only a few have been examined (Einhelling and Leather, 1988). The rest of the compounds, might contain very promising growth inhibitors are still unknown. Since about 12.5% of the total plants species of the world are considered as medicinal plants (Wakdikar, 2004), therefore, they could be served as important candidates for allelopathic research. Isolation and characterization of that unknown allelochemicals from medicinal plants might provide the chemical basis for new natural herbicides developments.

_Hyptis_, the genus of Lamiaceae contains approximately 400 species (Willis, 1973) and most of the species are native to the tropical America (Hutchinson and Dalziel, 1963; Hickey and King, 1988). However, one of the species _Hyptis suaveolens_ Poit distributed throughout the tropics and subtropics, along the rail tracks, roadsides (Mishra and Verma, 1992), foothills of open forests, forest clearings (Mudgal et al., 1997) and also in the fallow lands. _H. suaveolens_ has many medicinal properties and used for several ethnobotanical applications (Adda et al., 2011). For example, leaf decoction is used for the treatment of diabetes (Abdullahi et al., 2003) and cancer (Danmalam et al., 2009), and root decoction is highly valued as appetizer. Moreover, these organs contain urosolic acid, a natural HIV-integrase inhibitor (Chatterjee and Pakrashi, 1997). In addition, the leaves and twigs are considered as antispasmodic, antirheumatic, anti-inflammatory, antifertility agents (Kirtikar and Basu, 1991), and also have antiseptic, mosquitocidal and insecticidal properties (Shenoy et al., 2009; Adda et al., 2011). The leaves of _H. suaveolens_ contain alkaloids, terpenes and volatile oils (Gills, 1992). Beside the pharmacological and toxicological properties of _H. suaveolens_, still now very few are known about its allelopathic activities. Therefore, the current research was conducted to explore the allelopathic activity of _H. suaveolens_ on different test plant species.

(Materials and Methods)

**Plant materials**

Whole plants (leaves, stem and roots) of _H. suaveolens_ were collected from Bangladesh during the month of March-April, 2012. After collection, plants were washed with tap water to remove the soil and other debris followed by sun drying. The dried plants were then kept in a refrigerator at 2 °C temperature until extraction.

**Test plant species**

Eight test plant species, cress (_Lepidium sativum_ L.), lettuce (_Lactuca sativa_ L.), alfalfa (_Medicago sativa_ L.), rapeseed (_Brassica napus_ L.), timothy (_Phleum pratense_ L.), crabgrass (_Digitaria sanguinalis_ L. scop.), barnyardgrass (_Echinochloa crus-galli_ L.) and Italian ryegrass (_Lolium multiflorum_ Lam.) were selected for the present research. Among these eight test species, the first four are dicotyledonous and the rest are monocotyledonous. Cress, alfalfa, lettuce, rapeseed and timothy were chosen due to their known seedling growth, whereas crabgrass, barnyard grass and Italian ryegrass were chosen because they are most common weeds in the crop fields and distributed throughout the world.

**Extraction procedure**

The whole parts (leaves, stem and roots) of dried _H. suaveolens_ (30 g) were cut into small pieces and extracted with 300 mL of 70 % (v/v) aqueous methanol for 48 h. After filtration using one layer of filter paper (No. 2; Advantec® Toyo Roshi Kaisha, Ltd., Tokyo, Japan), the residue was re-extracted with 300 mL of 100% methanol for 24 h and filtered. The two filtrates were combined and evaporated with a rotary evaporator at 40°C.

**Germination bioassay**

An aliquot of the extract (final assay concentration was 3, 10, 30 and 100 mg DW equivalent extract/mL) was evaporated to dryness at 40°C in _vacuo_ by rotary evaporator, dissolved in methanol and added to a sheet of filter paper (No. 2) in a 2.8 cm Petri dish. The methanol was evaporated in a draft chamber then the filter paper was moistened with 0.6 mL of 0.05% (v/v) aqueous solution of Tween 20 (polyoxyethylene sorbitan monolaurate; Nacalai Tesque, Inc., Kyoto, Japan) which was used for surfactant and did not cause any toxic effects. Ten seeds of cress or Italian ryegrass were arranged on the filter paper in Petri-dishes. Control seeds were also sown on the filter paper moistened with Tween 20 without plant extracts. Then the Petri dishes were incubated in the dark chamber at 25°C. The germination bioassay was laid out using a completely randomized design with three replications. Seeds that showed the emergence of the radical by rupturing the seed coat were considered to be germinated as described by...
Barrôco et al. (2005) and Faria et al. (2005). Germination of seeds was recorded at every 12 h intervals for four days. The percentage of germination over control in each treatment was calculated using the following equation:

Germination (% of control) = \frac{G_T}{G_0} \times 100

Where,

\( G_T \) = average number of germinated seed in the treatment in each time of measurements

\( G_0 \) = average number of germinated seed in the control at the same time of measurements

**Growth bioassay**

Test samples of plant extracts were prepared and added to a sheet of filter paper (No. 2) in a 2.8 cm Petri dish, and the filter paper was moistened with 0.6 mL of 0.05% (v/v) aqueous solution of Tween 20 as described above. Then, 10 seeds of cress, lettuce, alfalfa, rapeseed or 10 germinated seeds of timothy (germinated in the darkness at 25°C for 72 h after overnight soaking), crabgrass (germinated in the darkness at 25°C for 120 h after 24 h incubation in the light chamber at 25°C), barnyardgrass or Italian ryegrass (germinated in the darkness at 25°C for 24 h after overnight soaking) were arranged on the filter paper in Petri-dishes. The hypocotyl/coleoptile and root lengths of the seedlings were measured at 48 h after incubation in darkness at 25°C. Control seeds were sown on the filter paper moistened with 0.6 mL of 0.05% (v/v) aqueous solution of Tween 20 without plant extracts. The same bioassay experiment was repeated twice with three replications in each case.

The inhibition percentage was calculated using the following equation:

\[ \text{Inhibition} \, (\%) = \left[1 - \frac{\text{length with aqueous methanol extract}}{\text{length of control}}\right] \times 100 \]

The concentrations required for 50% inhibition (express as \( I_{50} \)) of the test plant species in the assay was calculated from the regression equation of the concentration response curves.

**Statistical analysis**

Experimental data were analyzed using statistical software PASW statistics 17.0 (SPSS Inc., Illinois, USA) and GraphPad Prism 6.0 (GraphPad Software, Inc., California, USA).

**Results**

**Effects of \( H. \) suaveolens plant extracts on the germination of two test plant species**

The effects of aqueous methanol extracts of \( H. \) suaveolens on the germination of cress and Italian ryegrass were determined (Figure 1, 2). The extracts inhibited the germination and the inhibition was concentration dependent. The two-way ANOVA indicates that the four different concentrations, the period of incubations and their interaction have significant effect (p<0.001) on the germination of both cress and Italian ryegrass. The germination of cress was significantly inhibited by the \( H. \) suaveolens plant extracts at all extract concentrations. In contrast, the germination of Italian ryegrass was significantly inhibited at a concentrations ≥ 30 mg DW equivalent extract/mL (Figure 1, 2).

![Figure 1. Effects of aqueous methanol extracts of \( H. \) suaveolens on the germination of cress.](image-url)
A. K. M. Mominul Islam and Hisashi Kato-Noguchi

Figure 2. Effects of aqueous methanol extracts of *H. suaveolens* on the germination of Italian ryegrass. Means±SE from three independent experiments with 10 seeds for each determination are shown. All the values are statistically significant at p<0.001.

Figure 3. Effects of aqueous methanol extracts of *H. suaveolens* on hypocotyl/coleoptile growth of the test plant species. Means±SE from three independent experiments with 10 seedlings for each determination are shown. The negative (−) value in the Y axis indicates stimulation and positive (+) value indicates inhibition of the hypocotyl/coleoptile growth of eight test plant species by *H. suaveolens* plant extracts.

**Effects of *H. suaveolens* plant extracts on the growth of eight test plant species**

The inhibition percent of the aqueous methanol extracts of *H. suaveolens* on the hypocotyl/coleoptile and root growth of cress, lettuce, alfalfa, rapeseed, timothy, crabgrass, barnyardgrass and Italian ryegrass are shown in Figures 3 and 4. The hypocotyl/coleoptile and root growth of all but Italian ryegrass and alfalfa were significantly inhibited by the extracts at concentrations greater than 3 mg DW equivalent extract/mL. Moreover, the effectiveness of *H. suaveolens* plant extracts were different among test species, and the inhibition percent of the extracts was concentration dependent (Figure 3, 4). The two-way ANOVA showed that *H. suaveolens* plant extracts and its interaction with the eight test plant species has a significant (p<0.001) effect on the seedling growth of all the test plant species.
At the concentration of 30 mg DW equivalent extract/mL, the inhibition percent of the aqueous methanol extracts of *H. suaveolens* on hypocotyl/coleoptile growth of cress, lettuce, alfalfa, rapeseed, timothy, crabgrass, barnyardgrass and Italian ryegrass was 90, 80, 73, 39, 51, 36, 22 and 44, respectively (Figure 3). The hypocotyl growth of lettuce seedling was completely inhibited (Figure 5) when the seeds are applied to a concentration of 100 mg DW equivalent extract/mL, followed by alfalfa, timothy, cress, rapeseed, Italian ryegrass, crabgrass and barnyardgrass at 95, 92, 91, 87, 86, 66 and 58% inhibition, respectively. On the other hand, the extracts of *H. suaveolens* stimulated the hypocotyl/coleoptile growth of cress, alfalfa, timothy and Italian ryegrass at a concentration of 3 mg DW equivalent extract/mL. In addition, the coleoptile growth of Italian ryegrass was stimulated by the *H. suaveolens* at a concentration of 10 mg DW equivalent extract/mL (Figure 3). Considering the concentration required for 50% inhibition (defined as \(I_{50}\)), it was revealed that the hypocotyl growth of lettuce seedling was most sensitive to the aqueous methanol extracts of *H. suaveolens*, whereas the coleoptile growth of barnyardgrass was least sensitive (Table 1).

At the concentration of 30 mg DW equivalent/mL, the inhibition percent of the root growth of timothy, Italian ryegrass, cress, lettuce, crabgrass, rapeseed, barnyardgrass and alfalfa was 96, 95, 91, 82, 78, 75, 75 and 56, respectively (Figure 4). When the test plant species were exposed to the concentration of 100 mg DW equivalent extract/mL, the root growth of lettuce and Italian ryegrass seedling were completely (100%) inhibited (Figure 5, 6) followed by rapeseed, timothy, barnyardgrass, alfalfa, cress and crabgrass seedlings and the inhibition on their root growth was 97, 97, 95, 95, 91 and 83%, respectively. In contrast, the root growth of cress, alfalfa and Italian ryegrass were significantly stimulated by the *H. suaveolens* plant extracts at the concentration of 3 mg dry weight equivalent extract/mL (Figure 4). Furthermore, the root growth of alfalfa was stimulated by the extracts at a concentration of 10 mg DW equivalent extract/mL (Figure 4). Considering \(I_{50}\) value, the root growth of crabgrass was most sensitive to the *H. suaveolens* plant extracts than the other test plant species, whereas alfalfa was least sensitive to the extracts (Table 1).

**Discussion**

*H. suaveolens* is a ruderal type of plants that normally grows in a colony. It was reported that the other plant species near their colony is quite restricted (Raizada, 2006), but there have not so much clear evidence of the reasons. However, one of the main reasons for this character of the plant could be due to its allelopathic potentiality. A few evidences are found in the literature about the allelopathic activity of the leaf extracts and dry leaf residue of *H. suaveolens* plants. For example, Chatiyanon et al. (2012) reported that the water and methanol extract of the leaves of *H. suaveolens* has...
allelopathic effects on the germination and seedling growth of *Pennisetum setosum* (Swartz.) L.C. Rich and *Mimosa invisa* Mart. Similar findings were also reported by Kapoor (2011) who worked with dry leaf residue of *H. suaveolens* and observed inhibitory activity on the growth and physiological parameters of *Parthenium hysterocephorus* L. In the present research the aqueous methanol extracts of *H. suaveolens* significantly inhibited the germination of cress and Italian ryegrass at concentrations greater than 3 and 30 mg DW equivalent extract/mL, respectively. The extracts also significantly inhibited the seedling growth of all test plant species (cress, lettuce, alfalfa, rapeseed, timothy, crabgrass, barnyardgrass and Italian ryegrass) at concentrations greater than 10 mg DW equivalent extract/mL. These results imply that the aqueous methanol extract of *H. suaveolens* may possess allelochemicals which are responsible for their inhibitory activity. Moreover, the inhibitory activity of *H. suaveolens* plant extracts on different test species was concentration dependent. Concentration dependent inhibition on germination and growth by allelopathic plants extracts was also reported by Inderjit and Keating (1999), Kato-Noguchi et al. (2001), An et al. (2005), Bogatek et al. (2006) and Soltys et al. (2012).

Table 1. *I*$_{50}$ values of the aqueous methanol extract of *H. suaveolens* plant on hypocotyl/coleoptile and root growth of eight test plant species.

| Test plant species | *I*$_{50}$ (mg dry weight equivalent extract/mL) |
|--------------------|-----------------------------------------------|
|                    | Hypocotyl/Coleoptile growth | Root growth |
| Cress              | 10.0                           | 11.7        |
| Lettuce            | 9.3                            | 13.8        |
| Alfalfa            | 20.3                           | 29.5        |
| Rapeseed           | 37.7                           | 15.4        |
| Italian ryegrass   | 30.6                           | 9.5         |
| Barnyardgrass      | 79.3                           | 13.2        |
| Crabgrass          | 51.6                           | 4.9         |
| Timothy            | 25.3                           | 5.4         |

Note: The values were determined by a logistic regression analysis after bioassays.

The inhibitory activity of *H. suaveolens* plant extracts on the germination of cress and Italian ryegrass was congruent with the previous findings of many other researchers. They reported that the decrease of germination ability in presence of allelochemicals could be due to several
abnormalities created by the allelochemicals on seed during germination process. For example, Kato-Noguchi and Maicas (2006) reported that allelochemicals like 6-methoxy-benzoxazolin-2(3H)-one (MBOA) inhibit the germination of cress seeds by inhibiting the induction of α-amylase activity, which is very crucial for the conversion of reserve carbohydrate into soluble sugars during seed germination. Oracz et al. (2007) stated that the accumulation of reactive oxygen species caused cellular damage, which resulted in the decrease of germination ability and gradual loss of seed vigour. The decrease in germination ability was also due to enhanced membrane deterioration (Bogatek et al., 2006).

The root growth of all the test plant species was observed to be more sensitive to the *H. suaveolens* plant extracts than the hypocotyl/coleoptile growth. These results are in agreement with the earlier findings of Stachon and Zimdahl (1980) and Aliotta et al. (1993) who reported that allelopathic plant extracts had higher root growth inhibition than the coleoptiles. This phenomenon might be due to the more intensive contact between roots and plant extracts. Salam and Kato-Noguchi (2010) also reported that roots were more sensitive to the allelochemicals than hypocotyls/coleoptiles because the roots are the first organ to absorb allelochemicals from the environment. Whereas, Nishida et al. (2005) stated that the permeability of allelochemicals into root tissue is higher than the shoot tissue. They also explained that the hypocotyl/coleoptile growth of seedlings largely depends on cell expansion which is relatively insensitive to the allelochemicals, whereas root growth requires not only cell expansion, but also cell proliferation which is sensitive to the allelochemicals and therefore, the root growth exerts higher inhibition than the hypocotyl/coleoptile growth.

On the other hand, a number of abnormalities have been found when the test species are subjected to allelochemicals, and is the plausible cause for their growth inhibition. For example, allelochemicals inhibit the process of cell division, elongation and expansion rate, (Rice, 1984; Ortega et al., 1988; Einhellig, 1996; Jacob and Sarada, 2012), respiration process (Inderjit and Keating, 1999), ion absorption process (Qasem and Hill, 1989), enzyme activity (Sato et al., 1982), plant endogenous hormones and protein synthesis (Jacob and Sarada, 2012), alteration of the phytochrome control of germination (Leather and Einhellig, 1988) and consequently, arrested the plant growth. Allelochemicals may produce more than one effect of the above on the cellular processes that could be responsible for the reduced seedling growth of the test plant species. But the details of the biochemical mechanism through which allelochemicals exert a toxic effect on the growth of any plant species are still not well known (Zhou and Yu, 2006). Never the less, the stimulatory activity on the hypocotyl/coleoptiles and root growth of cress, alfalfa, timothy and Italian ryegrass by the aqueous methanol extract of *H. suaveolens* at a concentration less than 10 mg DW equivalent extract/mL are in line with the findings of many other researchers. They reported that allelochemicals can stimulate the seedlings growth at very low concentrations but inhibit the seedlings growth at high concentrations (Rice, 1984; Lovett et al., 1989; Liu and Chen, 2011; Islam and Kato-Noguchi, 2012). The stimulatory activity of any compound at low doses is called hormesis (Southam and Erlich, 1943). In some cases, allelochemicals have also been reported to induce hormesis. The reason behind the hormesis is due to the availability of some chemicals at lower doses which could affect the plant hormones that are responsible for shoot or root elongation, while they might have inhibitory activity on the seedling growth at higher doses due to the same or another mechanism of action (Duke et al., 2006).

**Conclusion**

The concentration dependent inhibitory activities of the aqueous methanol extracts of *H. suaveolens* on the germination and seedling growth of the test species suggest that the plant has allelopathic potentiality and possess allelochemicals. These allelochemicals could be the main reason for the restricted growth of other plant species near their colony. Isolation and identification of those allelochemicals from *H. suaveolens* could be act as lead for the development of bio-degradable, environment friendly new natural herbicides for sustainable weed management strategies. However, more research is necessary to further confirm the allelopathic potentiality of *H. suaveolens* under field and greenhouse conditions to make our predictions more accurate.

**Acknowledgements**

The authors wish to acknowledge Dr. A. K. M. Aminul Islam (Department of Genetics and Plant Breeding, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Bangladesh) for providing the plant materials to the authors. The Plant Protection Wing (Plant Quarantine), Department of
Agricultural Extension, Ministry of Agriculture, Government of the Peoples Republic of Bangladesh to give the permission to the authors for bringing the dried *H. suaveolens* plants from Bangladesh, and the financial assistance of Japanese Government (Monbukagakusho: MEXT) to carry out this research are also thankfully acknowledged.

**References**

Abdullahi, M., G. Muhammed and N. U. Abdulkadir. 2003. Medicinal and economic plants of Nupe land, Jube-Evans books and publications.

Adda, C., P. Atachi, K. Hell and M. Tamò. 2011. Potential use of the bushmint, *Hyptis suaveolens*, for the control of infestation by the pink stalk borer, *Sesamia calamistis* on maize in southern Benin, West Africa. J. Insect Sci. 11(33):1–13.

Aktar, M. W., D. Sengupta and A. Chowdhury. 2009. Impact of pesticides use in agriculture: their benefits and hazards. Interdisc. Toxicol. 2(1):1–12.

Aliotta, G., G. Cafeiro, A. Fiorentino and S. Strumia. 1993. Inhibition of raddish germination and root growth by coumarin and phenyl propanoides. J. Chem. Ecol. 19:175–183.

An, M., J. E. Pratley, T. Haig and D. L. Liu. 2005. Whole range assessment: a simple method for analyzing allelopathic dose response data. Nonlin. Biol. Toxicol. Med. 3:245–260.

Barróco, R. M., K. V. Poucke, J. H. W. Bergervoet, L. De Veylder, S. P. C. Groot, D. Inzé and G. Engler. 2005. The Role of the Cell Cycle Machinery in Resumption of Postembryonic Development. Plant Physiol. 137:127–140.

Bogatek, R., A. Gniazdowska, W. Zakrzewska, K. Oracz and S. W. Gawroński. 2006. Allelopathic effects of sunflower extracts on mustard seed germination and seedling growth. Biol. Plant. 50(1):156–158.

Chatiyanon, B., T. Tanee, C. Talumbook and C. Wongwattana. 2012. Effect of *Hyptis suaveolens* Poit leaf extracts on seed germination and subsequent seedling growth of *Pennisetum setosum* (Swartz.) L.C. Rich and *Mimosa invisa* Mart. Agric. J. 7(1):17–20.

Chatterjee, A. and S. C. Pakrashi. 1997. The treatise on Indian medicinal plants, Vol. 5, PID, New Delhi, India.

Danmalam, U. H., L. M. Abdullahi, A. Agunu and K. Y. Musa. 2009. Acute toxicity studies and hypoglycemic activity of the methanol extract of the leaves of *Hyptis suaveolens* Poit. (Lamiaceae). Nigerian J. Pharma. Sci. 8(2):87–92.

Duke, S. O., N. Cedergreen, E. D. Velini and R. G. Belz. 2006. Hormesis: is it an important factor in herbicide use and allelopathy? Outlooks Pest Manage. 29–33.

Einhellig, F. A. 1996. Mechanism of action of allelochemicals in allelopathy. Agron. J. 88:886–893.

Einhellig, F. A. and G. R. Leather. 1988. Potentials for exploiting allelopathy to enhance crop production. J. Chem. Ecol. 14:1829–1844.

Faria, J. M. R., J. Buitink, A. A. M. van Lammeren and H. W. M. Hilhorst. 2005. Changes in DNA and microtubules during loss and re-establishment of desiccation tolerance in germinating *Medicago truncatula* seeds. J. Exp. Bot. 56(418):2119–2130.

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

Gills, L. S. 1992. Ethnomedicinal uses of plants in Nigeria, University of Benin Press, Benin City, Nigeria, p. 276.

Han, C. M., K. W. Pan, N. Wu, J. C. Wang and W. Li. 2008. Allelopathic effect of ginger on seed germination and seedling growth of soybean and chive. Sci. Hor. 116(3):330–336.

Hickey, M. and C. King. 1988. 100 families of flowering plants. Cambridge: Cambridge University Press.

Hutchinson, J. and J. M. Dalziel. 1963. Flora of West Tropical Africa, Crown Agents; London.

Inderjit and K. I. Keating. 1999. Allelopathy: principles, procedures, processes, and promises for biological control. Adv. Agron. 67:141–231.

Islam, A. K. M. M. and H. Kato-Noguchi. 2012. Allelopathic potentiality of medicinal plant *Leucas aspera*. Internat. J. Sust. Agric. 4(1):1-7.
Jacob, J. and S. Sarada. 2012. Role of phenolics in allelopathic interactions. Allelopathy J. 29(2):215–230.

Kapoor, R. T. 2011. Bio-herbicidal potential of leaf residue of Hyptis suaveolens on the growth and physiological parameters of Parthenium hysterephorus L. Curr. Res. J. Biol. Sci. 3(4):341–350.

Kato-Noguchi, H. 2001. Effects of lemon balm (Melissa officinalis L.) extract on germination and seedling growth of six plants. Acta Physiol. Plant. 23(1):49–53.

Kato-Noguchi, H. and F. A. Macias. 2006. Possible mechanism of inhibition of 6-Methoxy Benzoazololin-2(3H)-One on germination of cress (Lepidium sativum L.). J. Chem. Ecol. 31:1187–1203.

Khan, M. Z. and F. C. P. Law. 2005. Adverse effects of pesticides and related chemicals on Enzyme and hormone systems of fish, amphibians and reptiles: A review. Proc. Pakistan Acad. Sci. 315–323.

Kirtikar, K. R. and B. D. Basu. 1991. Indian medicinal plants. Singh B and Singh MP Publishers, India.

Leather, G. R. and F. A. Einhellig. 1988. Bioassay of naturally occurring allelochemicals of phytotoxicity. J. Chem. Ecol. 14:1821–1828.

Li, H., K. W. Pan, Q. Liu and J. C. Wang. 2009. Effect of enhanced ultraviolet-B on allelopathic potential of Zanthoxylum bungeanum. Sci. Hor. 119(3):310–314.

Lin, D., E. Tsuzuki, Y. Sugimoto, Y. Dong, M. Matsuo and H. Terao. 2003. Assessment of dwarf Lily turf (Ophiopogon japonicus K.) dried powders for weed control in transplanted rice. Crop Prot. 22(2):431–435.

Lin, D., E. Tsuzuki, Y. Sugimoto, Y. Dong, M. Matsuo and H. Terao. 2004. Elementary identification and biological activities of phenolic allelochemicals from dwarf Lily turf plant (Ophiopogon japonicus K.) against two weeds of paddy rice field. Plant Prod. Sci. 7(3):260–265.

Liu, Y. and X. Chen. 2011. Mathematical modeling of plant allelopathic hormesis based on ecological-limiting-factor models. Dose Resp. 9:117–129.

Lovett, J. W., M. Y. Ryuntyu and D. L. Liu. 1989. Allelopathy, chemical communication, and plant defence. J. Chem. Ecol. 15:1193–1202.

Mishra, B. K. and B. K. Verma. 1992. Flora of Allahabad district, Uttar Pradesh, India. Singh B and Singh MP Publishers.

Mudgal, V., K. K. Khanna and P. K. Hazra. 1997. Flora of Madhya Pradesh II: Botanical Survey of India.

Nishida, N., S. Tamotsu, N. Nagata, C. Saito and A. Sakai. 2005. Allelopathic effects of volatile monoterpenoids produced by Salvia leucophylla: inhibition of cell proliferation and DNA synthesis in the root apical meristem of Brassica campestris seedlings. J. Chem. Ecol. 31:1187–1203.

Oracz, K., C. Bailly, A. Gniazdowska, D. Come, F. Corbino and R. Bogatek. 2007. Induction of oxidative stress by sunflower phytotoxins in germinating mustard seeds. J. Chem. Ecol. 33:251–264.

Ortega, R. C., A. L. Anaya and L. Ramos. 1988. Effects of allelopathic compounds of corn pollen on respiration and cell division of watermelon. J. Chem. Ecol. 14:71–86.

Pell, M., B. Stenberg and L. Torstensson. 1998. Potential denitrification and nitrification tests for evaluation of pesticide effects in soil. Ambio. 27:24–28.

Qasem, J. R. and T. R. Hill. 1989. Possible role of allelopathy in competition between tomato, Senecio vulgaris L. and Chenopodium album L. Weed Res. 29:349–356.

Raizada, P. 2006. Ecological and vegetative characteristics of a potent invader, Hyptis suaveolens Poit. from India. Lyonia 11(2):115–120.

Rice, E. L. 1984. Allelopathy, 2nd Edn., Academic press, London.

Salam, M. A. and H. Kato-Noguchi. 2010. Allelopathic potential of methanol extract of Bangladesh rice seedlings. Asian J. Crop Sci. 2:70–77.

Sato, T., F. Kiuchi and U. Sankawa. 1982. Inhibition of phenyalanine ammonia-lyase by cinnamic acid derivatives and related compounds. Phytochemistry 21:845–850.

Shenoy, C., M. B. Patil and R. Kumar. 2009. Wound Healing Activity of Hyptis suaveolens

700
(L.) Poit (Lamiaceae). Internat. J. Pharm. Tech. Res. 1(3):737–744.

Sodaeizadeh, H., M. Rafieiolhossaini, J. Havlik and P. Van Damme. 2009. Allelopathic activity of different plant parts of *Peganum harmala* L. and identification of their growth inhibitors substances. Plant Growth Regul. 59:227–236.

Soltys, D., R. Bogatek and A. Gniazdowska. 2012. Phytotoxic effects of cyanamide on seed germination and seedling growth of weed and crop species. Acta Biol. Cracov. Bot. 54(2):87–92.

Southam, C. M. and J. Erlich. 1943. Effects of extract of western red-cedar heartwood on certain wood-decaying fungi in culture. Phytopath. 33:517–524.

Stachon, W. J. and R. L. Zimdahl. 1980. Allelopathic activity of Canada thistle (*Cirsium arvense*) in Colorado. Weed Sci. 28:83–86.

Swain, T. 1977. Secondary compounds as protective agents. Ann. Rev. Plant Physiol. 28:479–501.

Vyvyan, J. R. 2002. Allelochemicals as leads for new herbicides and agrochemicals. Tetrahedron. 58:1631–1646.

Wakdikar, S. 2004. Global health care challenge: Indian experiences and new prescriptions. Electr. J. Biotechnol. 7(3):214-220.

Willis, J. C. 1973. Dictionary of Flowering Plants and Ferns, (Rev. by Shaw, A. K.) Cambridge University Press; London.

Wilson, C. and C. Tisdell. 2001. Why farmers continue to use pesticides despite environmental, health and sustainability costs. Ecol. Econ. 39:449–462.

Zhou, Y. H. and J. Q. Yu. 2006. Allelochemicals and photosynthesis, In: M. J. Reigosa, N. Pedrol and L. Gonzalez (Eds.). pp. 127–139. Allelopathy: A Physiological Process with Ecological Implications. Springer, The Netherlands.