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Research Paper

Determination of allelopathic potentials in plant species in Sino-Japanese floristic region by sandwich method and dish pack method

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Abstract

The Sino-Japanese Floristic Region appears as one of the major centers of development of higher plants. This region have been relevant for the study of evolution and systematics of many flowering plants. The taxonomic richness of endemic plant species in this region have survived several years of extreme climate conditions. Endemic mountainous plant species that have survived extreme climate conditions are of allelopathic and medicinal interest. For this reason, 251 plant species collected from the Sino-Japanese Floristic Region were screened for allelopathic plant species. Sandwich method and dish pack method were respectively used to screen plant leaf leachates and volatile materials with lettuce (*Lactuca sativa* CV. Great Lakes 366) as receptor plant. Among the 84 species that showed inhibitory effect on lettuce radicle elongation in our sandwich bioassay, *Photinia glabra* showed complete inhibition of lettuce radicle elongation (0% radicle elongation). In the dish pack bioassay, *Photinia glabra*, *Liquidambar styraciflua*, and *Cinnamomum camphora* (90.6%, 61.4%, and 50.2% respectively) were among the nine species that were observed with strong inhibitory effect on lettuce radicle growth. On the other hand, nine other species promoted lettuce radicle growth when compared to the control. *Aesculus turbinata* and *Quercus gilva* were the species with the highest growth stimulatory effect (33.0% and 16.1% respectively). We hereby present *Photinia glabra* as an allelopathic candidate species for both leachate and volatile compounds.

Keywords: *Allelochemicals; Dish Pack Method; Elongation; Leaf Leachates; Sandwich Method; Sino-Japanese Floristic Region.*

1. Introduction

Some living organisms especially plants, have the inherent ability to interfere with biological activities of other organism(s) in their immediate vicinity by releasing certain compounds, this phenomenon is termed as allelopathy. The term allelopathy describes beneficial and mostly harmful natural interactions between organisms due to the release of bioactive secondary metabolites from the donor organism. These secondary metabolites associated with this phenomenon are called allelochemicals which are mostly introduced into the environment through volatilization, leaching, root exudation, and/or by the decomposition of plant residues [1]. Majority of allelochemicals are products of secondary metabolism with a few resulting from primary metabolism [2]. From an ecological perspective, allelopathy may play an important role in the process of biological invasion. Some invasive plant species are perceived to be successful because they possess novel compounds that function as allelopathic agents or as mediators of the new plant-plant interactions [3]. Some effects of allelochemicals on the growth and development of susceptible plants include; reduced radicle and shoot extension, darkened and/or swollen seeds, curling of root axis, discoloration of seeds, lack of root hairs, necrosis, increased number of seminal roots, and reduced dry weight accumulation among others [4]. Modern agricultural practices have succeeded due to the discovery and adoption of agrochemicals for pest control. However, there have been 452 unique cases of herbicide resistant/tolerant weeds among 245 species [5]. Nonetheless, it is difficult

to estimate the cost associated with yield losses due to only herbicide-resistant/tolerant weeds [6]. Due to the increasing number of herbicide-resistant/tolerant weeds and environmental concerns about the inappropriate use of synthetic herbicides, efforts have been made towards developing alternate sustainable weed management strategies. Plants that are able to suppress and/or eliminate competing plant species have received much attention, and the possibilities of using compounds from such plants as selective natural herbicides have increased [7, 8]. Isolated bioactive substances (allelochemicals) from plants are therefore important sources for alternate agrochemicals which could help reduce some of the problems arising from poor cultural practices and excessive use of synthetic pesticides [9]. These natural agrochemicals, compared to their synthetic counterparts are expected to have shorter half-lives in the environment and hence considered to be more environmentally friendly [10]. Over the last decade, there have been a growing market for products from organic farming [11]. Consequently, current researches in weed management have focused much attention on the use of natural products (allelochemicals) as natural pesticides in order to reduce the effects of synthetic pesticides on environment and human health, and to promote sustainable agriculture [12]. These have called for the screening for growth inhibitory plants and the subsequent isolation of their active compounds. This study focused on plants in the Sino-Japanese Floristic Region in East Asia which have one of the most diverse temperate floras in the world. The flora of this region holds special interest for the study of the history of temperate floras of the northern hemisphere. Several plant species of different genera have been reported to be endemic in this region [13]. Qian, [14] reported that the taxonomic richness of seed plants of East Asia is significantly more diverse compared to North America with approximately twice as many plant species as eastern North America, which holds similar size and environment. High physiographical heterogeneity is considered to be of major influence on the extremely high floral diversity within the Sino-Japanese Floristic Region [15]. During the exceptionally cold periods of climate change, the series of mountains (usually with elevations of about 2000 m) in this region provided diverse habitats allowing for species survival. Cool environments at higher elevations are suitable for survival of relict populations in modern subtropics. These relict population may however had allowed for the divergence between extant populations [16]. Recently, the allelopathic potential of certain plant species especially those with medicinal properties have been reported. In this study, we present the comprehensive screening of allelopathic activity of some plants in this region using the sandwich and dish pack methods. The basis of current weed control researches towards identifying potent bioactive compound(s) for weed control is the screening of large quantities of plants. Potential allelopathic candidate species would be identified from the screening process to pave way for further researches. We examined 256 plant samples from 251 different plant species for their allelopathic potentials under laboratory conditions. This report only focused on identifying and introducing allelopathic potentials in some plant species of Sino-Japanese region, while another report will focus on the identification of allelopathic compounds in species that exhibited strong allelopathic potentials for growth inhibitors.

2. Materials and methods

2.1. Plant samples and preparation

The collection of plant samples focused on a part of Japan and China called the Sino-Japanese Floristic Region. A total of 256 plant samples were collected from seven different locations; including the campus of Tokyo University of Agriculture and Technology (TUAT), Tsukuba Botanical Gardens (TKBG), Tokyo Medicinal Botanical Garden (TMBG), Wuhan Botanical Garden (WHBG), Kunming Botanical Garden (KMBG), South China Botanical Garden, (SCBG), and South China University of Agriculture (SCUA). The leaves and other parts of each plant species were freshly collected, placed in separate paper bags and oven-dried (60℃ for 24 hours). The samples were then kept in an air-tight box until further use. The oven-dried samples were used for laboratory studies in the Laboratory of International Agro-Biological Resources and Allelopathy at Tokyo University of Agriculture and Technology, Japan.

2.2. Sandwich method

The sandwich method adopted from Fujii et al., [17] was used to determine the allelopathic activity of leachates from selected donor plant leaves. This method have been used [18, 19, 20] to screen large quantity of plants and is effective in determining allelopathic activities by plant leachates under laboratory conditions. Using this method, 251 plant samples (245 species) were screened. Using multi-well plastic dish, the sandwich method was set up as shown in Fig. 1. Treatments were replicated three times and data presented as the mean of the three replicates. Agar with no plant material was set as the untreated control. The multi-well plastic plates were completely randomized in an incubator (NTS Model MI-25S) at 25°C for three days after which radicle and hypocotyl lengths were measured.

2.3. Dish pack method

Fujii et al., [21] adopted this approach to screen for the presence of volatile allelochemicals from plant species. This method is widely used [22] because it determines the presence of volatile allelochemicals in plants very quickly. Using

this method, 69 plant species were screened for possible volatile substances that can influence (promote or inhibit) the growth of lettuce. Multi-well plastic dishes with 6 wells (36 mm×18 mm each) were used in this experiment. The distances from the center of the source well (where plant sample was placed) to the center of other wells were 41, 58, 82, and 92 mm (Fig. 2). The source well was filled with 200 mg of oven-dried plant material, while filter papers were laid in the other wells and 0.75 ml of distilled water was added to each of the wells containing filter paper. The control treatment did not contain any plant sample at the source well. Seven lettuce seeds (*Lactuca sativa* var. Great Lakes 366) were placed on the filter paper in each well. The multi-well dishes were tightly sealed using cellophane tape to avoid desiccation and loss of volatile compounds. To exclude light, aluminum foils were wrapped around the dishes and placed in an incubator (NTS Model MI-25S) at 25°C for three days. The radicle and hypocotyl lengths were measured and recorded after 3 days of incubation and compared to that of the control. The degree of inhibition were estimated by the relationship between lettuce seedling growth inhibition and its distance from the source well.

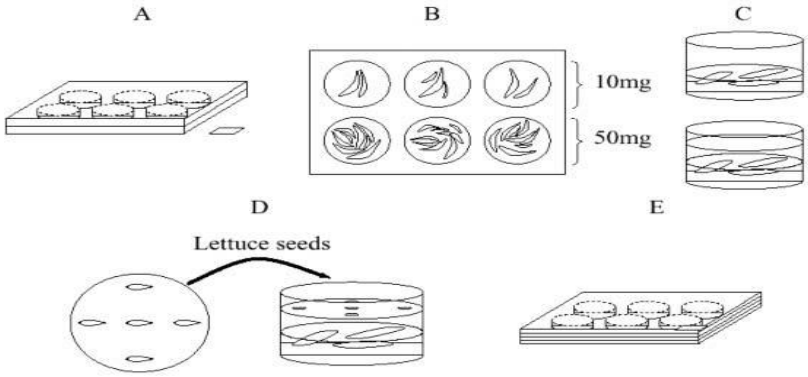


Fig. 1: Sandwich Method: (A) Multi-well plastic plate with six wells; (B) 10 Or 50 mg dried plant material placed in each well of the multi-well plastic plate; (C) Addition of 5 mL plus 5 mL agar (Nacalai Tesque Agar Powder, 0.75% w/v autoclaved for 20 minutes at 120°C) in two layers on the oven-dried plant material; (D) Five seeds (*Lactuca Sativa* Var. Great Lakes 366) Lettuce seeds vertically placed; (E) Covered with plastic tape and appropriately labelled the multi-well plastic plates for incubation in dark conditions [17].

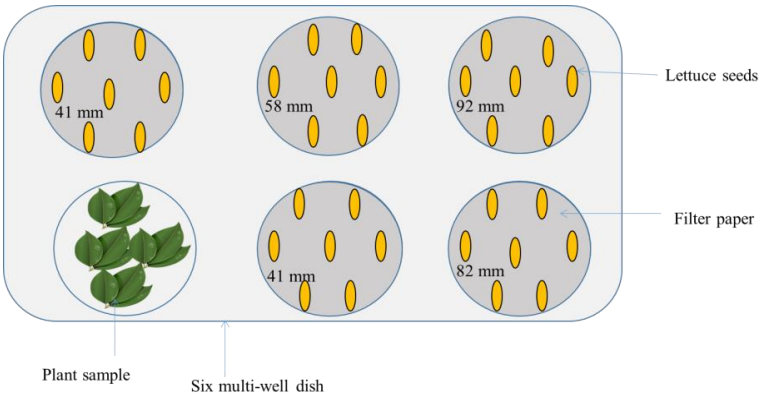


Fig. 2: View from top of Multi-well plastic plate used to test for plant allelopathy through volatile substances.

2.4. Statistical analysis

The experimental set-up was arranged in a complete randomized design with three replicates. In the statistical analysis, evaluation of the means, standard deviation (SD), and SD variance (SDV) were done using Microsoft Excel 2007.

$$\text{Elongation \%} = \frac{\text{(Average length of treatment radicle/hypocotyl)}}{\text{(Average length of control radicle/hypocotyl)}} \quad (1)$$

$$\text{Inhibitory \%} = 100 - \frac{\text{(Average length of treatment radicle/hypocotyl)}}{\text{(Average length of control radicle/hypocotyl)}} \quad (2)$$

3. Results

3.1. Allelopathic effects of leachates from oven-dried plant materials on lettuce

The percentage elongation of radicle and hypocotyl of lettuce seedlings (1) as affected by leachates from 245 plant species based on sandwich method is shown in Table 1. In this study, the radicle elongations percentages of lettuce

seedlings were in the range 0-123% and 0-105% of the untreated control when respectively treated with 10 mg and 50 mg of oven-dried leaves. In both 10 mg and 50 mg of oven-dried leaf treatment, lettuce radicle elongations were inhibited more than hypocotyl elongations. With respect to 10 mg oven dried leaves treatment, it was observed that 84 species caused significant inhibition on lettuce radicle as evaluated using standard deviation variance (SDV). The families with the highest number of different plant species examined were Magnoliaceae (16 species), Rosaceae, and Fabaceae (11 species each), Fagaceae (8 species) with Oleaceae, Moraceae, and Araliaceae have 7 species each. Only the Rosaceae and Amaryllidaceae families had two species that had lettuce radicle elongation less than 29% of control with Anacardiaceae and Malvaceae having one species each. Further, Boraginaceae, Alistolochiaceae, Euphorbiaceae, Berberidiaceae, Taxaceae, Magnoliaceae, Hemerocallidaceae, and Rutaceae (one species each) showed lettuce radicle elongation in the range 29.5-39.8% of control. It was also found that the oven-dried leaves of six species showed the strongest inhibitory activity on lettuce seedling, showing radicle elongation in the range of 0-29% of the untreated control for 10 mg treatment. These species include; *Photinia glabra*, *Dracontomelon duperreanum*, *Hibiscus syriacus*, *Amygdalus persica*, *Lycoris aurea*, and *Lycoris radiata*. Eight other species (*Cordia dichotoma*, *Asarum nipponicum*, *Bischofia polycarpa*, *Mahonia lomariifolia*, *Taxus wallichiana*, *Magnolia liliiflora*, *Hemerocallis fulva*, and *Acronychia pedunculata*) showed strong inhibitory activity on lettuce seedling with radicle elongation in the range of 29.5-39.8% of the untreated control for 10 mg treatment. In lettuce radicle elongation of 38.9-50.2% of the untreated control, 18 different species were observed when treated with 10 mg oven-dried leaves. The lowest inhibitory activity in this study was observed in 52 plant species with lettuce radicle elongation for 10 mg treatment in the range of 50.3-60.6% of the untreated control. In terms of inhibition on lettuce hypocotyl elongation, only two species *P. glabra* and *A. persica* (both Rosaceae) could cause the strongest reduction (<29.5%) in this study. Among the 251 plant samples evaluated, only *P. glabra* could completely reduce both lettuce radicle and hypocotyl elongations to 0% for both 10 mg and 50 mg oven-dried leaves treatment. *Photinia glabra* (Rosaceae) was ranked the strongest inhibitory plant species among the evaluated species using the sandwich method.

3.2. Effects of volatiles compounds from plant species on lettuce seedlings in dish pack method

Table 2 shows the effects (inhibition or promotion) on radicle and hypocotyl of lettuce seedlings that were grown in dish packs containing oven-dried leaves from 69 different plant species. The effects of the plant leaves on growth of lettuce radicle and hypocotyl (2) were presented either as promotion or inhibition. Lettuce radicle growth values indicated negative represent promotional effect when compared to the corresponding control. Our results indicate that among the 69 plant species tested, lettuce radicle growth was either inhibited or stimulated by 9 different species each when compared to the control. Strongest inhibitory effects were shown in seven families, including Rosaceae (two), Taxadiaceae (two), with Altingiaceae, Lauraceae, Pinaceae, Rubiaceae, and Juglandaceae having one species each for different plant species. Only *Photinia glabra* was observed among the 69 plant species tested to have inhibited lettuce radicle growth more than 90%. It was also observed that two other species (*Liquidambar styraciflua* and *Cinnamomum camphora*) showed lettuce radicle growth inhibition in the range of 50-62%. Six other species including, *Metasequoia glyptostroboides*, *Sciadopitys verticillata*, *Amygdalus persica*, *Pinus parviflora*, *Platycarya strobilacea*, and *Gardenia sootepensis* demonstrated lettuce radicle inhibitory effect in the region of 31-39%. Moreover, *Aesculus turbinata* showed stimulatory effect on lettuce growth more than 25%, whereas *Quercus gilva*, *Diospyros kaki*, *Prunus buergeriana*, *Cephalotaxus fortunei*, and *Fraxinus longicuspis* demonstrated lettuce growth stimulation in the range of 10-24%. *Polyalthia longifolia*, *Magnolia obovata*, and *Acer mono*, showed the least stimulatory effect (6.0-9.8%) on lettuce radicle growth.

4. Discussion

Our study indicated that among 251 plant species studied, 10 species showed very strong inhibitory activity on radicle and hypocotyl lengths of lettuce seedling. Currently, there have been no allelopathic reports on six of these species (*Photinia glabra*, *Liquidambar styraciflua*, *Hibiscus syriacus*, *Lycoris aurea*, *Cordia dichotoma*, and *Asarum nipponicum*). Nonetheless, these plants contain some phytochemicals that are linked to phytotoxicity and the inhibition effects observed in these plant species may be due to these compounds or some unknown chemical constituents. We however introduce these compounds in this report. Another report will focus on the identification of bioactive compounds with allelopathic capabilities associated with some of these plant species. Among the species of the Rosaceae family in this study, *Photinia glabra* had the greatest inhibition on lettuce radicle growth in both sandwich and dish pack methods. *P. glabra* is native to Japan and have been widely planted for its attractive bright-red new leaf growth and grows 15 to 20 feet in height [23]. The leaves of *P. glabra* produced two biphenyl compounds when inoculated with fungal spores and treated with $HgCl_2$. These two biphenyl compounds (2'-methoxyaucuparin and 4'-methoxyaucuparin) are reasoned to be produced in response to microbial attack [24]. These phytoalexins from *P. glabra* and other plant species from the Rosaceae family can inhibit several pathogens especially fungi but their usefulness are however still limited [25]. Hirai et al., [26] reported that plants in the Rosaceae family contain sorbitol which is synthesized from glucose-6-phosphate during photosynthesis in the leaves of these plants. Ishikura, [27] reported that the fruits of *P. glabra* contain anthocyanin identified as cyaniding 3-monoglucoside.

Table 1: Radicle and hypocotyl elongation percentages of lettuce seedlings grown on agar gel containing oven-dried plant materials tested using the sandwich method.

Plant families	POC	Scientific Name	Dry leaf content (10 ml agar^{-1})				Criteria
			10 mg		50 mg		
			R%	H%	R%	H%	
Acanthaceae	WHUN	*Adhatoda vasica* Nees	55.6	115	24.2	91.2	*
	WHUN	*Gendarussa vulgaris* Nees	62.2	145	22.9	80.0	
Aceraceae	TUAT	*Acer pictum* Thunb.	55.2	92.6	26.1	83.3	*
	TUAT	*Acer buergerianum* Miq.	59.5	105	22.2	70.8	*
	TUAT	*Acer cissifolium* K. Koch	61.5	88.2	16.2	43.2	
	TUAT	*Acer palmatum* Thunb.	67.4	87.5	27.2	85.8	
	TUAT	*Acer diabolicum* Blume ex K. Koch	83.9	120	26.8	81.1	
Acoraceae	WHUN	*Acorus gramineus* Aiton	59.3	126	20.1	67.7	*
Actinidiaceae	TSUK	*Actinidia arguta* Franch. & Sav.	65.6	83.8	46.7	123	
	TSUK	*Actinidia rufa* Franch. & Sav.	88.1	111	35.0	87.1	
Aristolochiaceae	TSUK	*Asarum nipponicum* F. Maek.	33.6	82.9	16.7	76.3	***
Altingiaceae	TUAT	*Liquidambar styraciflua* L.	83.5	114	59.1	95.8	
Amaryllidaceae	WHUN	*Lycoris radiata* Herb.	26.3	92.0	8.70	35.2	****
	SCBG	*Lycoris aurea* Herb.	23.2	72.5	0.0	0.0	****
Anacardiaceae	WHUN	*Spondias lakonensis* Pierre	72.8	101	50.0	73.0	
	SCBG	*Dracontomelon duperreanum* Pierre	13.1	40.4	12.6	44.8	*****
Annonaceae	SCBG	*Artabotrys hexapetalus* (L. f.) Bhandari	58.1	84.2	28.3	69.0	*
	SCAU	*Polyalthia longifolia* (Sonn.) Thwaites	76.0	123	31.1	118	
Apiaceae	KUMN	*Peucedanum decumbens* Maxim.	64.4	91.4	41.6	78.5	
Apocynaceae	SCBG	*Alstonia scholaris* (L.) R. Br.	52.1	91.9	29.9	87.6	*
	SCBG	*Tabernaemontana divaricata* (L.) R. Br. ex Roem. & Schult.	58.1	91.2	31.3	65.5	*
	SCBG	*Wrightia pubescens* R. Br.	73.2	109	49.5	97.1	
Aquifoliaceae	SCBG	*Ilex ferruginea* Hand.-Mazz.	56.2	110	35.5	84.9	*
	TUAT	*Ilex crenata* Thunb.	76.3	127	75.4	124	
	SCBG	*Ilex rotunda* Thunb.	96.3	175	51.2	111	
	TUAT	*Ilex integra* Thunb.	98.6	120	78.2	122	
Arecaceae	SCBG	*Livistona fengkaiensis* X. W. Wei & M. Y. Xiao	56.0	97.5	42.3	80.4	*
Araceae	SCBG	*Alocasia macrorrhizos* (L.) G. Don	60.6	122	52.0	115	*
	WHUN	*Pothos chinensis* (Raf.) Merr.	47.6	107	19.5	51.3	**
Araliaceae	WHUN	*Acanthopanax* sessiliflorus Seem.	46.4	116	24.4	75.4	**
	SCAU	*Schefflera octophylla* Harms	65.9	130	21.9	59.6	
	TUAT	*Hedera rhombea* Siebold & Zucc.	67.2	109	36.3	86.8	
	TSUK	*Aralia cordata* Thunb.	107	164	48.0	151	
	KUMN	*Acanthopanax simonii* C. K. Schneid	73.2	91.4	59.8	81.5	
	TSUK	*Aralia elata* (Miq.) Seem.	86.5	109	27.1	86.5	
	WHUN	*Hedera nepalensis* K. Koch	60.4	106	29.4	105	*
Arecaceae	SCBG	*Rhapis excelsa* (Thunb.) A. Henry	61.1	94.7	30.8	72.4	
	SCBG	*Arenga tremula* Becc.	82.9	109	64.1	111	
	SCBG	*Caryota urens* L.	95.3	129	91.7	149	
	SCAU	*Areca triandra* Roxb. ex Buch.-Ham.	114	123	94.0	125	
	SCBG	*Arenga pinnata* Merr.	71.2	94.7	43.9	75.9	
Asparagaceae	TSUK	*Hosta sieboldiana* (Hook.) Engl.	43.3	59.2	34.4	58.8	**
	WHUN	*Asparagus albus* L.	105.3	134	89.0	135	
Asteraceae	TSUK	*Ligularia fischeri* Turcz.	50.2	88.3	26.7	64.9	*
	TSUK	*Chrysanthemum japonicum* (Maxim.) Makino	71.8	106	24.0	51.5	
	TSUK	*Aster ageratoides* Turcz.	85.3	110	65.2	103	
	TSUK	*Chrysanthemum pacificum* Nakai	50.9	102	73.3	104	*
	TSUK	*Stevia rebaudiana* Bertoni.	111	113	53.3	113	
Berberidaceae	KUMN	*Mahonia lomariifolia* Takeda	35.1	67.2	26.8	53.8	***
	TSUK	*Nandina domestica* Thunb.	47.3	68.9	26.2	47.4	**
	SCBG	*Mahonia fortunei* hort. ex Dippel	54.8	76.6	29.9	81.4	*
Betulaceae	TUAT	*Betula platyphylla* Sukaczev	83.7	104	65.2	108	
Bignoniaceae	SCBG	*Mayodendron igneum* Kurz	56.0	90.3	28.0	82.5	*

Plant families	POC	Scientific Name	Dry leaf content (10 ml agar^{-1})				Criteria
			10 mg		50 mg		
			R%	H%	R%	H%	
Bignoniaceae	WHUN	*Tecomaria capensis* (Thunb.) Spach	62.8	112	38.0	120	
	SCBG	*Dolichandrone cauda-felina* Benth. & Hook. f.	82.4	106	35.2	87.6	
Bombacaceae	SCBG	*Bombax malabaricum* DC.	59.1	114	49.0	79.3	*
	WHUN	*Ceiba speciosa* (A. St.-Hil., A. Juss. & Cambess.) Ravenna	68.0	107	26.8	90.8	
Boraginaceae	SCBG	*Cordia dichotoma* G. Forst.	30.7	75.7	17.8	73.5	***
	SCAU	*Ehretia thyrsiflora* Nakai	58.1	109	40.4	96.5	*
Brassicaceae	SCBG	*Isatis indigotica* Fortune	53.5	123	32.8	74.1	*
Buxaceae	WHUN	*Buxus sinica* (Rehder & E. H. Wilson) M. Cheng	55.2	81.0	31.6	75.4	*
Caprifoliaceae	TUAT	*Viburnum odoratissimum* Ker Gawl.	78.1	99.2	65.5	124	
Celastraceae	SCBG	*Euonymus bungeanus* Maxim.	45.9	84.2	47.5	129	**
	WHUN	*Perrottetia racemosa* (Oliv.) Loes.	65.1	129	39.1	99.4	
	TUAT	*Microtropis japonica* Hallier f.	83.8	115	74.6	116	
	TSUK	*Euonymus japonicus* L. f.	95.2	117	51.2	96.8	
Cephalotaxaceae	WHUN	*Cephalotaxus fortunei* Hook.	87.9	138	68.6	124	
Cercidiphyllaceae	TUAT	*Cercidiphyllum japonicum* Siebold & Zucc.	67.3	109	47.0	102	
Chloranthaceae	WHUN	*Sarcandra hainanensis* (C. Pei) Swamy & I. W. Bailey	76.5	142	35.6	108	
Clusiaceae	TSUK	*Hypericum ascyron* L.	94.7	92.2	47.1	87.6	
Convallariaceae	KUMN	*Aspidistra elatior* Blume	62.9	90.0	42.6	79.4	
Coriariaceae	TSUK	*Coriaria japonica* A. Gray	79.7	104	46.3	90.7	
Cornaceae	TUAT	*Benthamidia japonica* (Siebold & Zucc.) H. Hara	91.3	99.0	44.9	110	
Corylaceae	TUAT	*Carpinus tschonoskii* Maxim.	81.3	118	78.0	121	
Cupressaceae	TUAT	*Juniperus chinensis* L.	88.7	102	75.1	105	
	TSUK	*Sequoia sempervirens* (D. Don) Endl.	90.0	114	57.0	119	
	KUMN	*Sabina pingii* (W. C. Cheng ex Ferre) W. C. Cheng & W. T. Wang	100	121	91.4	117	
	TUAT	*Chamaecyparis pisifera* (Siebold & Zucc.) Endl.	116	127	94.9	135	
Cyatheaceae	SCBG	*Sphaeropteris lepifera* (Hook.) R. M. Tryon	103	126	76.0	117	
Cyperaceae	TSUK	*Carex oahuensis* Hillebr.	57.6	60.2	57.9	75.3	*
Daphniphyllaceae	KUMN	*Daphniphyllum longeracemosum* Rosenth.	79.4	91.4	68.4	93.8	
Dilleniaceae	SCBG	*Dillenia turbinata* Finet & Gagnep.	60.2	113	26.7	69.9	*
Dipterocarpaceae	SCBG	*Hopea chinensis* (Merr.) Hand.-Mazz.	59.4	56.8	26.3	54.9	*
	SCAU	*Hopea hainanensis* Merr. & Chun	119	136	60.1	107	
Dryopteridaceae	WHUN	*Cyrtomium yamamotoi* Tagawa	94.3	133	59.8	90.8	
Ebenaceae	TUAT	*Diospyros kaki* L. f.	108	119	69.5	89.9	
Elaeocarpaceae	SCAU	*Elaeocarpus apiculatus* Mast.	94.6	117	23.5	43.9	
	KUMN	*Sloanea hemsleyana* Rehder & E. H. Wilson	96.9	98.3	48.3	41.5	
Ericaceae	TUAT	*Rhododendron kaempferi* Planch.	61.6	85.9	31.0	65.3	
	TSUK	*Pieris japonica* D. Don ex G. Don	114	148	105	154	
Escalloniaceae	KUMN	*Itea yunnanensis* Franch.	86.2	124	64.1	110	
Euphorbiaceae	SCBG	*Bischofia polycarpa* (H.Lév.) Airy Shaw	34.8	80.6	12.2	31.1	***
	SCBG	*Sapium biglandulosum* Müll.Arg.	44.4	52.6	17.8	27.5	**
	WHUN	*Excoecaria acerifolia* Didr.	45.1	91.0	16.8	45.2	**
	WHUN	*Excoecaria cochinchinensis* Lour.	73.7	129	63.1	97.6	
	SCAU	*Bridelia tomentosa* Blume	86.2	179	20.8	82.5	
Fabaceae	SCBG	*Cassia siamea* Lam.	40.6	66.7	14.6	63.7	**
	SCBG	*Erythrophleum fordii* Oliv.	42.4	56.1	37.9	100	**
	TSUK	*Crotalaria sessiliflora* L.	53.6	88.9	20.8	55.9	*

Plant families	POC	Scientific Name	Dry leaf content (10 ml agar^{-1})				Criteria
			10 mg		50 mg		
			R%	H%	R%	H%	
Fabaceae	SCBG	*Pongamia pinnata* (L.) Pierre	55.4	98.2	32.3	100	*
	WHUN	*Wisteria sinensis* (Sims) DC.	56.5	82.7	67.0	87.9	*
	TUAT	*Styphnolobium japonicum* (L.) Schott	59.7	115	26.5	84.6	*
	SCBG	*Sindora tonkinensis* A. Chev.	73.2	114	54.8	115	
	SCBG	*Saraca dives* Pierre	60.6	111	49.5	107	*
	SCBG	*Pithecellobium lucidum* Benth.	64.6	135	47.5	143	
	SCBG	*Bauhinia blakeana* Dunn	65.1	74.8	33.5	85.0	
	TSUK	*Macroptilium atropurpureum* (L.) Urb.	99.5	107	34.2	100	
Fagaceae	TUAT	*Quercus myrsinifolia* Blume	75.4	106	93.6	122	
	TUAT	*Quercus glauca* Thunb.	80.6	109	45.2	95.9	
	TUAT	*Lithocarpus glaber* Nakai	81.1	108	62.3	131	
	TUAT	*Quercus gilva* Blume	82.4	90.1	68.5	81.1	
	TUAT	*Lithocarpus edulis* Nakai	84.9	105	61.4	114	
	TUAT	*Quercus serrata* Murray	86.3	104	54.8	107	
	SCAU	*Lithocarpus glaber* Nakai	111	153	74.3	132	
	TUAT	*Quercus acutissima* Carruth.	95.1	124	64.0	121	
Ginkgoaceae	TUAT	*Ginkgo biloba* L.	80.8	108	25.6	79.2	
	TUAT	*Ginkgo biloba* L. (Fruit)	83.5	106	30.1	69.4	
Hamamelidaceae	KUMN	*Loropetalum chinense* Oliv.	61.6	98.7	31.1	66.7	
	SCBG	*Altingia chinensis* Oliv. ex Hance	73.7	105	57.1	119	
	TUAT	*Hamamelis japonica* Siebold & Zucc.	76.9	115	57.4	103	
Hemerocallidaceae	TSUK	*Hemerocallis fulva* L.	35.5	69.9	36.2	73.2	***
Hippocastanaceae	TUAT	*Aesculus turbinata* Blume	71.0	96.3	61.7	109	
Hydrangeaceae	TSUK	*Hydrangea macrophylla* (Thunb.) Ser.	65.9	80.1	55.9	100	
Iridaceae	SCBG	*Iris japonica* Thunb.	52.5	89.2	23.5	63.7	*
Juglandaceae	TUAT	*Platycarya strobilacea* Siebold & Zucc.	67.6	117	38.9	86.8	
Lamiaceae	SCBG	*Vitex quinata* F. N. Williams	60.2	88.3	23.1	65.5	*
	TSUK	*Callicarpa japonica* Thunb.	60.4	76.7	48.0	92.8	*
	SCBG	*Epimeredi indica* (L.) Rothm.	69.2	119	44.4	81.0	
	TSUK	*Scutellaria baicalensis* Georgi	72.2	108	41.9	97.7	
	KUMN	*Callicarpa macrophylla* Vahl	87.4	113	62.6	99.1	
	TSUK	*Keiskea japonica* Miq.	107	159	41.8	123	
Lardizabalaceae	TSUK	*Akebia quinata* (Thumb. ex Houtt.) Decne.	65.7	104	55.2	86.4	
	TSUK	*Stauntonia hexaphylla* Decne.	94.7	120	66.1	147	
Lauraceae	WHUN	*Lindera fragrans* Oliv.	62.2	95.3	41.7	87.3	
	SCBG	*Machilus oculodracontis* Chun	69.2	107	30.3	68.9	
	WHUN	*Cinnamomum osmophloeum* Keneh.	76.0	110	42.7	62.6	
	SCAU	*Cinnamomum burmannii* (Nees & T. Nees) Blume	88.6	108	45.9	91.2	
	TUAT	*Laurus nobilis* L.	68.7	118	42.3	77.1	
	SCBG	*Cinnamomum porrectum* (Roxb.) Kosterm.	73.2	96.5	70.7	112	
	TUAT	*Cinnamomum camphora* (L.) J. Presl	82.2	108	54.7	121	
	SCBG	*Litsea verticillata* Hance	74.3	107	52.0	96.5	
Liliaceae	SCBG	*Tupistra glandistigma* Wang et Tang	65.7	92.1	35.3	72.5	
Davalliaceae	KUMN	*Nephrolepis cordifolia* (L.) K. Presl	88.3	122	65.1	120	
Lythraceae	SCBG	*Lagerstroemia speciosa* (L.) Pers.	81.7	125	17.5	63.9	
	TUAT	*Lagerstroemia indica* L.	85.8	117	36.7	91.0	
Magnoliaceae	SCBG	*Magnolia liliiflora* Desr.	35.4	64.9	26.3	56.9	***
	SCBG	*Manglietia lucida* B. L. Chen & S. C. Yang	64.8	82.0	35.9	95.6	
	SCBG	*Magnolia sirindhorniae* Noot. & Chalermglin	69.7	100	23.8	45.1	
	SCBG	*Manglietia insignis* Blume	71.3	123	37.6	97.1	
	TUAT	*Magnolia obovata* Thunb.	73.1	105	44.0	73.4	
	TUAT	*Magnolia grandiflora* L.	84.7	100	81.3	121	

Plant families	POC	Scientific Name	Dry leaf content (10 ml agar^{-1})				Criteria
			10 mg		50 mg		
			R%	H%	R%	H%	
Magnoliaceae	TUAT	*Liriodendron tulipifera* L.	85.8	106	45.3	92.2	
	SCAU	*Michelia balansae* Dandy	102	145	61.7	147	
	SCAU	*Michelia sphaerantha* C.Y. Wu ex Z.S. Yue	88.0	104	61.2	94.7	
	SCAU	*Michelia fadouensis* D. X. Li & Y. W. Law	104	172	76.5	121	
	TUAT	*Magnolia Kobus* DC.	105	164	61.9	113	
	KUMN	*Michelia figo* (Lour.) Spreng.	59.3	96.6	31.1	64.6	*
	KUMN	*Michelia yunnanensis* Franch. ex Finet & Gagnep.	80.1	88.8	60.3	73.0	
	SCAU	*Michelia alba* DC.	78.2	80.7	75.4	78.4	
	SCAU	*Manglietia fordiana* Oliv.	102	160	50.3	130	
	SCAU	*Tsoongiodendron odorum* Chun	123	149	84.7	147	
Malvaceae	SCBG	*Hibiscus syriacus* L.	14.6	75.4	5.6	32.8	*****
	SCBG	*Hibiscus mutabilis* L.	61.6	146	24.2	75.9	
Meliaceae	SCBG	*Aglaia odorata* Lour.	92.4	118	51.2	96.5	
Moraceae	TUAT	*Morus bombycis* Koidz.	49.1	106	15.3	70.8	**
	SCBG	*Ficus drupacea* Thunb.	49.5	96.5	23.2	87.9	**
	SCBG	*Ficus fistulosa* Reinw. ex Blume	59.0	91.9	32.4	96.5	*
	SCBG	*Ficus benjamina* L.	72.4	128	31.0	66.4	
	SCAU	*Ficus lacor* Buch.-Ham.	86.2	127	27.9	86.0	
	SCBG	*Ficus annulata* Blume	92.4	184	49.5	160	
	WHUN	*Ficus microcarpa* L. f.	72.8	117	40.4	111	
Myricaceae	TSUK	*Myrica rubra* (Lour.) Siebold & Zucc.	84.5	116	67.0	110	
Myrsinaceae	TSUK	*Ardisia crenata* Roxb.	60.1	84.7	35.6	62.7	*
	WHUN	*Rapanea neriifolia* (Siebold & Zucc.) Mez	84.6	166	43.1	104	
Myrtaceae	SCBG	*Eugenia javanica* Lam.	83.3	112	45.5	106	
Oleaceae	SCBG	*Osmanthus matsumuranus* Hayata	52.0	104	27.8	89.7	*
	TUAT	*Ligustrum lucidum* W. T. Aiton	80.2	103	47.3	103	
	KUMN	*Ligustrum compactum* (Wall. ex G. Don) Hook. f. & Thomson ex Brandis	83.3	97.8	72.9	83.5	
	SCBG	*Osmanthus fragrans* Lour.	84.6	149	65.4	121	
	TUAT	*Fraxinus longicuspis* Siebold & Zucc.	86.1	90.9	81.5	125	
	TUAT	*Osmanthus fragrans* Lour.	88.7	103	89.6	128	
	WHUN	*Olea europaea* L.	86.6	93.3	82.4	71.3	
Orchidaceae	TSUK	*Epipactis thunbergii* A. Gray	61.1	78.9	67.7	71.0	
Oxalidaceae	SCBG	*Averrhoa carambola* L.	67.0	115	22.8	73.5	
Papaveraceae	KUMN	*Corydalis taliensis* Franch.	55.9	70.0	26.3	37.6	*
Pinaceae	TUAT	*Pinus parviflora* Siebold & Zucc.	73.2	104	46.2	88.4	
	TUAT	*Pinus thunbergii* Parl.	82.5	81.5	39.6	57.5	
Piperaceae	WHUN	*Piper sarmentosum* Roxb.	39.9	94.8	14.5	65.8	**
	SCBG	*Piper sarmentosum* Roxb.	64.6	105	49.5	95.6	
Platanaceae	TUAT	*Platanus orientalis* L.	90.2	116	71.9	127	
Poaceae	WHUN	*Indocalamus tessellatus* (Munro) Keng f.	56.2	91.3	34.0	89.7	*
	TSUK	*Miscanthus condensatus* Hack.	57.9	82.2	46.2	88.2	*
Podocarpaceae	SCAU	*Nageia nagi* Britton & P.Wilson	102	143	77.6	89.5	
	SCAU	*Podocarpus fleuryi* Hickel	115	117	55.2	68.4	
Primulaceae	TSUK	*Lysimachia daphnoides* Hillebr.	74.3	101	16.3	47.4	
Ranunculaceae	KUMN	*Anemone vitifolia* Buch.-Ham. ex DC.	54.1	80.9	38.9	59.1	*
	TSUK	*Caltha palustris* L.	60.5	111	37.4	104	*
Rhamnaceae	TSUK	*Ziziphus jujuba* Mill.	59.5	94.4	23.1	59.1	*
	SCBG	*Sageretia thea* (Osbeck) M. C. Johnst.	80.8	124	48.4	104	
Rosaceae	KUMN	*Photinia glabra* (Thunb.) Maxim.	0.0	0.0	0.0	0.0	*****
	TSUK	*Amygdalus persica* L.	17.1	29.1	13.1	26.8	*****
	TUAT	*Prunus buergeriana* Miq.	51.2	112	17.2	81.8	*
	TUAT	*Cerasus jamasakura* (Koidz.) H. Ohba	57.2	89.0	57.3	88.1	*

Plant families	POC	Scientific Name	Dry leaf content (10 ml agar^{-1})				Criteria
			10 mg		50 mg		
			R%	H%	R%	H%	
Rosaceae	TUAT	*Prunus yedoensis* Matsum.	77.1	113	56.4	109	
	KUMN	*Laurocerasus undulata* (Buch.-Ham. ex D. Don) M. Roem.	59.0	82.0	33.7	60.0	*
	KUMN	*Prinsepia utilis* Royle	77.6	94.4	61.0	82.6	
	TUAT	*Eriobotrya japonica* (Thunb.) Lindl.	87.6	134	72.0	135	
	TUAT	*Prunus lannesiana* E. H. Wilson	88.0	103	50.2	89.0	
	TSUK	*Spiraea japonica* L. f.	111	166	66.2	149	
	TUAT	*Cerasus speciosa* (Koidz.) H. Ohba	75.9	99.2	41.3	97.6	
Rubiaceae	SCBG	*Gardenia sootepensis* Hutch.	70.1	91.0	35.9	79.6	
	SCBG	*Psychotria rubra* Poir.	77.3	118	37.9	89.7	
Rutaceae	SCBG	*Acronychia pedunculata* Miq.	39.4	84.2	28.8	75.9	***
	SCBG	*Atalantia buxifolia* (Poir.) Oliv.	46.0	97.5	49.0	119	**
	TSUK	*Phellodendron amurense* Rupr.	53.1	88.3	20.7	67.8	*
	SCBG	*Clausena lansium* Skeels	66.3	118	25.1	86.4	
	TUAT	*Citrus junos* Siebold ex Tanaka	84.0	109	49.8	114	
Sapindaceae	SCBG	*Dimocarpus longan* Lour.	52.9	108	23.8	95.6	*
	TUAT	*Sapindus mukorossi* Gaertn.	60.0	104	25.6	53.4	*
	WHUN	*Litchi chinensis* Sonn.	83.8	117	58.0	109	
Sapotaceae	SCBG	*Madhuca pasquieri* H. J. Lam	41.8	74.8	18.5	81.4	**
Saxifragaceae	TSUK	*Astilbe microphylla* Knoll	70.6	108	36.5	92.5	
Schisandraceae	SCBG	*Kadsura coccinea* (Lem.) A. C. Sm.	44.8	90.1	15.7	47.8	**
Solanaceae	KUMN	*Anisodus acutangulus* C. Y. Wu & C. Chen	44.9	116	25.5	106	**
	SCBG	*Datura metel* L.	63.0	122	39.2	133	
Sterculiaceae	SCAU	*Pterospermum heterophyllum* Hance	113	153	65.6	132	
Styracaceae	TUAT	*Styrax japonica* Siebold & Zucc.	66.9	91.4	49.4	80.3	
Symplocaceae	SCBG	*Symplocos cochinchinensis* (Lour.) S. Moore	47.9	94.2	18.5	41.7	**
Taxaceae	KUMN	*Taxus wallichiana* Zucc.	35.1	98.2	36.0	54.8	***
	WHUN	*Taxus chinensis* Roxb.	56.2	128	35.4	102	*
	TUAT	*Torreya nucifera* Siebold & Zucc.	98.5	128	73.9	104	
Taxodiaceae	TUAT	*Metasequoia glyptostroboides* Hu & W. C. Cheng	53.7	116	14.8	92.4	*
	TSUK	*Metasequoia glyptostroboides* Hu & W. C. Cheng	56.7	78.6	29.4	66.0	*
	TUAT	*Taxodium distichum* (L.) Rich.	82.9	117	33.0	78.5	
	TUAT	*Cryptomeria japonica* D. Don	107	121	88.9	117	
Theaceae	SCBG	*Camellia oleifera* C. Abel	50.4	80.7	14.1	45.8	*
	TSUK	*Camellia sasanqua* Thunb.	71.0	75.6	26.5	32.3	
	TUAT	*Ternstroemia gymnanthera* (Wight & Am.) Bedd.	75.6	107	69.6	115	
	SCAU	*Schima spp*	77.2	166	35.5	119	
	TUAT	*Camellia sasanqua* Thunb.	83.6	110	56.1	78.0	
Thymelaeaceae	KUMN	*Daphne papyracea* Wall. ex Steud.	41.5	111	24.8	66.1	**
Tropaeolaceae	TSUK	*Tropaeolum majus* L.	60.0	116	31.2	73.2	*
Ulmaceae	TUAT	*Aphananthe aspera* Planch.	65.2	119	38.4	97.2	
	TUAT	*Zelkova serrata* (Thunb.) Makino	71.8	138	35.4	129	
Ulmaceae	TUAT	*Celtis sinensis* Pers.	88.3	112	45.6	113	
Urticaceae	TSUK	*Boehmeria tenuifolia* Satake	70.2	113	30.4	108	
Valerianaceae	TSUK	*Patrinia villosa* Juss.	86.9	118	57.0	112	
Verbenaceae	KUMN	*Duranta erecta* L.	43.3	77.6	7.7	26.2	**
Zingiberaceae	WHUN	*Hedychium coccineum* Buch.-Ham. ex Sm.	66.0	100	31.1	80.0	
	WHUN	*Alpinia oxyphylla* Miq.	54.3	109	24.7	70.9	*
	WHUN	*Amomum tsaoko* Crevost & Lemarie	67.9	149	21.8	90.4	

* Criteria Indicates stronger inhibitory activity of test sample on the radicle elongation of lettuce by standard deviation variance (SDV) where: * = M–0.5(SD), ** = M–1.0(SD), *** = M–1.5(SD), **** = M–2.0(SD), and ***** = M–2.5(SD). Thus SDV of 61, 50, 40, 29, and 19 respectively. Plant species with more * indicates increasing inhibitory activity. M: mean of radicle elongation, SD: standard deviation of radicle length, R: Radicle, H: Hypocotyl, %: elongation percentage of control. Values close to 0% indicate strong inhibitory activity in that plant species. POC; Place of collection.

Table 2: Determination of allelopathic activity by volatile compounds in some plant species in the Sino-Japanese Region using the dish pack method

Plant families	POC	Scientific name	Inhibition activity				Criteria
			Average for whole wells		Average at 41 mm		
			R%	H%	R%	H%	
Aceraceae	TUAT	*Acer cissifolium* K. Koch	22.9	33.6	33.0	35.7	
	TUAT	*Acer palmatum* Thunb.	12.7	8.0	23.5	21.1	
	TUAT	*Acer diabolicum* Blume ex K. Koch	11.9	-0.8	13.1	-8.4	
	TUAT	*Acer buergerianum* Miq.	-2.8	-9.2	3.4	-14.6	
	TUAT	*Acer mono* Maxim.	-9.8	-6.6	14.3	-0.4	+
Amaryllidaceae	WHBG	*Lycoris radiata* Herb.	23.1	20.2	32.6	31.5	
Annonaceae	SCAU	*Polyalthia longifolia* (Soon.) Thwaites	-7.6	0.5	-18.6	-6.6	+
Altingiaceae	TUAT	*Liquidambar styraciflua* L.	61.4	2.8	61	3.1	***
Arecaceae	SCAU	*Areca triandra* Roxb. ex Buch.-Ham.	21.4	21.7	30.8	29.9	
Asparagaceae	TKBG	*Hosta sieboldiana* (Hook.) Engl.	21.7	11.3	24.5	13.3	
Asteraceae	TKBG	*Ligularia fischeri* Turcz.	10.3	8.9	11.0	10.1	
Berberidaceae	TKBG	*Nandina domestica* Thunb.	22.1	13.1	26.2	25.4	
Betulaceae	TUAT	*Betula platyphylla* Sukaczev	-2.3	-10.9	-1.8	-12.4	
Bombacaceae	SCBG	*Bombax malabaricum* DC.	-3.3	-15.3	-3.9	-25.7	
Caprifoliaceae	TUAT	*Viburnum odoratissimum* Ker Gawl.	2.1	-2.7	3.5	-1.7	
Cephalotaxaceae	WHBG	*Cephalotaxus fortunei* Hook.	-10.3	-12.9	-1.9	-1.1	++
Cercidiphyllaceae	TUAT	*Cercidiphyllum japonicum* Siebold & Zucc.	27.0	9.1	31.8	6.7	
Cornaceae	TUAT	*Benthamidia japonica* (Siebold & Zucc.) H. Hara	13.9	-24.6	6.7	-37.7	
Cupressaceae	TUAT	*Juniperus chinensis* L.	24.5	18.5	34.0	15.1	
Daphniphyllaceae	KMBG	*Daphniphyllum longeracemosum* Rosenth.	3.5	-6.8	8.2	2.6	
Dipterocarpaceae	SCAU	*Hopea hainanensis* Merr. & Chun	3.9	1.5	8.1	2.2	
Ebenaceae	TUAT	*Diospyros kaki* L. f.	-11.0	-10.9	-15.7	-17	+
Elaeocarpaceae	SCAU	*Elaeocarpus apiculatus* Mast.	20.0	21.1	23.2	21.1	
Fabaceae	SCBG	*Saraca dives* Pierre	2.4	4.2	5.4	5.6	
	WHBG	*Wisteria sinensis* (Sims) DC.	0.4	-1.1	4.5	0.3	
Fagaceae	TUAT	*Lithocarpus edulis* Nakai	22.7	1.9	27.0	13.9	
	TUAT	*Quercus serrata* Murray	4.5	-5.3	8.9	5.5	
	TUAT	*Quercus gilva* Blume	-16.1	-6.4	-11.3	-5.7	++
Ginkgoaceae	TUAT	*Ginkgo biloba* L.	12.9	-9.2	13.2	-12.9	
Hamamelidaceae	TUAT	*Hamamelis japonica* Siebold & Zucc.	11.3	7.8	4.0	3.2	
Hippocastanaceae	TUAT	*Aesculus turbinata* Blume	-33.0	-7.9	-23.1	-7.0	+++
Juglandaceae	TUAT	*Platycarya strobilacea* Siebold & Zucc.	34.9	17.9	45.0	9.7	*
Lamiaceae	KMBG	*Callicarpa macrophylla* Vahl.	1.3	1.6	5.1	1.9	
Lauraceae	TUAT	*Cinnamomum camphora* (L.) J. Presl	50.2	59.9	43.7	63.0	***
	TUAT	*Laurus nobilis* L.	3.6	5.0	7.0	6.6	
Liliaceae	SCBG	*Tupistra glandistigma* Wang et Tang	1.8	1.6	4.1	3.0	
Lythraceae	SCBG	*Lagerstroemia speciosa* (L.) Pers.	3.6	0.9	5.2	1.6	
Magnoliaceae	TUAT	*Liriodendron tulipifera* L.	19.1	7.8	16.1	13.6	
	SCAU	*Michelia balansae* Dandy	12.8	-40.5	21.6	-32.9	
	SCBG	*Magnolia liliiflora* Ders.	10.7	1.6	21.1	7.9	
	SCAU	*Manglietia fordiana* Oliv.	10.1	0.0	19.1	-1.3	
	SCAU	*Tsoongiodendron odorum* Chun	7.2	0.8	9.2	-0.7	
	TUAT	*Magnolia grandiflora* L.	4.8	-2.2	2.0	-12.3	
	SCAU	*Magnolia megaphylla* (Hu & W. C. Cheng) V. S. Kumar	1.4	2.6	4.1	0.0	
	TUAT	*Magnolia kobus* DC.	-3.1	2.1	2.8	8.7	
	TUAT	*Magnolia obovata* Thunb.	-8.2	-6.8	0.3	-1.1	+
Moraceae	TKBG	*Morus alba* L.	27.1	17.0	29.7	19.3	
Myrtaceae	SCBG	*Eugenia javanica* Lam.	12.0	9.0	23.6	18.0	
Oleaceae	TUAT	*Fraxinus longicuspis* Siebold & Zucc.	-10.0	-4.1	-4.9	2.3	+
	TUAT	*Ligustrum lucidum* W. T. Aiton	10.9	6.7	12.5	7.9	
Pinaceae	TUAT	*Pinus parviflora* Siebold & Zucc.	35.5	29.9	35.7	29.8	*

Plant families	POC	Scientific name	Inhibition activity				Criteria
			Average for whole wells		Average at 41 mm		
			R%	H%	R%	H%	
Platanaceae	TUAT	*Platanus orientalis* L.	1.8	-4.1	-1.1	-2.5	
Podocarpaceae	SCAU	*Podocarpus fleuryi* Hickel	4.9	8.5	10.4	15.3	
Rosaceae	TUAT	*Cerasus speciosa* (Koidz.) H. Ohba	4.6	-10.3	18.2	-11.2	
	TKBG	*Amygdalus persica* L.	36.2	28.9	41.0	44.1	*
	KMBG	*Photinia glabra* (Thunb.) Maxim.	90.6	86.1	95.2	90.2	***
	TUAT	*Prunus yedoensis* Matsum.	13.1	-1.4	24.0	-3.3	
	TUAT	*Prunus jamasakura* Siebold ex Koidz.	11.8	9.1	13.0	14.9	
	TUAT	*Prunus lannesiana* E. H. Wilson	4.3	-4.3	7.3	7.6	
	TUAT	*Prunus buergeriana* Miq.	-10.8	-2.6	-2.4	7.2	+
Rubiaceae	SCBG	*Gardenia sootepensis* Hutch.	32.0	24.3	41.4	31.2	*
Sapindaceae	TUAT	*Sapindus mukorossi* Gaertn.	17.9	7.1	22.1	12.9	
	WHBG	*Litchi chinensis* Sonn.	12.0	0.5	21.1	7.9	
Schisandraceae	SCBG	*Kadsura coccinea* (Lem.) A. C. Sm.	17.1	3.7	26.7	8.7	
Styracaceae	TUAT	*Styrax japonica* Siebold & Zucc.	13.9	12.2	27.7	17.3	
Taxodiaceae	TUAT	*Metasequoia glyptostroboides* Hu & W. C. Cheng	42.0	22.5	47.3	20.5	**
	TUAT	*Sciadopitys verticillata* Siebold & Zucc.	38.4	37.3	42.0	49.3	*
Ulmaceae	TUAT	*Zelkova serrata* (Thunb.) Makino	12.9	2.3	14.4	12.4	
Zingiberaceae	WHBG	*Alpinia oxyphylla* Miq.	29.0	26.4	34.5	39.6	

* Criteria (*), (**), and (***) refer to radicle elongation shorter than the mean value plus 1.0(SD), 1.5(SD) and 2(SD), that is, SDV = 31, 40, and 50, respectively. + Criteria (+), (++), and (+++) refer to radicle elongation longer than the mean value minus 1.0(SD), 1.5(SD) and 2(SD), that is, SDV = -6, -10, and -25, respectively. POC; Place of Collection. TUAT; Tokyo University of Agriculture and Technology, TKBG; Tsukuba Botanical Gardens, TMBG; Tokyo Medicinal Botanical Garden, WHBG Wuhan Botanical Garden, KMBG; Kunming Botanical Garden, SCBG; South China Botanical Garden, SCUA; South China University of Agriculture.

Another species of interest in this family is *Amygdalus persica* which is a fruit of ornamental importance. *A. persica* is native to China where it have been cultivated for centuries [28]. Dried seeds of *A. persica* have been used in combination with other herbal plants to overcome stroke-induced disability [29], [30]. *A. persica* have been reported as a non-food biodiesel plant resources based on grey relation analysis with extremely complicated genetic diversity [31]. Glucosid amygdalin and hydrocyanic acid are the principal constituents of *A. persica* [32]. In the Malvaceae family, species that showed strong inhibition on lettuce radicle elongation was *Hibiscus syriacus*. *Hibiscus syriacus* is native to tropical climates, but are grown around the world for medicinal use and aesthetic value. *H. syriacus* have been used to treat ailments like gastrointestinal disorders, fevers, respiratory disorder as cough, used as emollient [33]. Sporopollenin observed from pollen of *H. syriacus* have a simple aliphatic polymer containing aromatic or conjugated side chains as the main structure [34]. In a screening for lipid peroxidation inhibitors, Yoo et al., [35] isolated three naphthalene compounds: 2,7-dihydroxy-6-methyl-8-methoxy-1-naphthalenecarboxaldehyde, 2-hydroxy-6-hydroxymethyl-7,8-dimethoxy-1-naphthalene-carboxaldehyde, and 1-carboxy-2,8-dihydroxy-6- methyl-7-methoxynaphthalenecarbolactone, designed as syriacusins A–C, from the chloroform extract of the root bark of *H. syriacus*. All the three compounds inhibited lipid peroxidation. Novel cyclic peptide Hibispeptin a ($C_{39}H_{50}N_60_8$) and Hibispeptin B ($C_{36}H_{52}N_6O_8$) have been isolated from the root bark of *H. syriacus* [36], [37].

In the Boraginaceous family, *Cordia dichotoma* had the highest inhibition on lettuce radicle elongation. *Cordia dichotoma* have been listed as non-consensus invasive woody plant in the coastal and dry lowlands in Mauritius [38]. This species have been used traditionally in India to treat ulcerative colitis (UC) and colic pain. Ganjare et al., [39] showed that apigenin isolated from the bark of *Cordia dichotoma* was responsible for the treatment of UC since it showed significant healing and reduction in inflammation enzymes when screened against UC. Polysaccharide in fruit of *Cordia dichotoma* is a potential candidate for use as herbal excipient in the formulation of orodispersible tablets [40]. The leaves and bark of *Cordia dichotoma* have shown high antioxidant, antimicrobial and ant implantation activities [41], [42], and [43]. The leaves have been found to contain querecetin and quecitrin whereas arabinoglucan, L-arabinose and D-glucose have been found in the fruits [44].

Another species that showed strong inhibitory potential through the volatiles released is *Liquidambar styraciflua* (also known as sweetgum) of the family Altingiaceae. The major components of the leaf oil were reported to be styrene, d-limonene, α-pinene and β-pinene, and that of the stem oil were germacrine D, α-cadinol, d-limonene, α-pinene, and β-pinene [45], [46]. These essential oils showed anti-inflammatory activity with low cytotoxicity thus backing its traditional use in treating inflammation. The emission of isoprene from sweetgum has been shown to be dependent on light and severe drought conditions [47], [48]. Some influenza viruses and the virus responsible for H1N1 are susceptible to the antiviral Tamiflu®. Shikimic acid is a precursor of oseltamivir phosphate which is the key ingredient

in Tamiflu®. However, much of the shikimic acid manufactured are generated by an *Escherichia coli* that produces shikimic acid [49], [50], [51]. *Liquidambar styraciflua* were found to contain shikimic acid in the bark and seeds [52], [53] and can potentially produce commercial quantities. 25-Acetoxy-3α-en-28-oic acid and 3β, 25-epoxy-3α-hydroxylup-20(29)-en-28-oic acid isolated from the cones of *Liquidambar styraciflua* showed moderate anti-tumor promoter [54].

In the Amaryllidaceae family, leachates from *L. radiata* and *L. aurea* all highly inhibited the lettuce radicle elongation. The Amaryllidaceae family are mostly cultivated as ornamental plants and some are used as folk medicines for the treatment of some ailments [55]. The genus Lycoris comprises about 20 species that are wildly distributed in eastern Asia wood-lands, China and Japan in particular [56]. The allelochemical in *L. radiata* has been identified as lycorine [57]. However, allelopathy of *L. aurea* have not been reported. The bulb of *L. aurea* have been used in China to heal fractured bones [58]. Lycosinine A & B have been isolated from the bark of this species [59]. New alkaloids such as 2α-hydroxy-6-O-n-buty-loduline, O-n-butyllycorenine and (-)-N-(Chloromethyl) lycoramine have been isolated from the bulb of *L. aurea*. All the compounds exhibited significant neuro-protective effects against $CoCl_2$ and H_2O_2-induced Sh-SY5Y cell death [55]. Pi et al., [60] reported that some alkaloids isolated from bulb of *L. aurea* showed significant cytotoxicity against all tumor cell line (seven) tested. The alkaloids 3-0-ethyltazettinol 2α-methoxy-6-O-ethyloduline have also been isolated from the bulb of *L. aurea* [61], [62].

5. Conclusion

The results from this study hereby provide brief insight on the allelopathic potentials of some plants in the Sino-Japanese Floristic Region. Further research can be conducted on the identification and characterization of allelochemicals using this data as benchmark information. Information as such could aid in the development of bioactive compounds from plant species into natural herbicides and also the utilization of these plants in sustainable weed control. We will present in our subsequent report the allelochemical(s) responsible for the inhibitory activity in *Photinia glabra* which was the strongest allelopathic species in this study.

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Conflict of interest

The authors declare that there is no conflict of interest associated with this publication.

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