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Invited Review

Current research status of allelopathy of plants grown in Bangladesh

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Abstract

Allelopathy is probably involved in all aspects of natural ecosystems such as competition and succession of plant communities. Much of research in allelopathy mentioned that allelopathy can be used to control weeds and to reduce synthetic chemical input into agriculture practices. Several important papers describing allelopathy and allelopathic active substances in plants in Bangladesh have published in the last decay. Hundreds of plant species including about 150 rice cultivars in Bangladesh were evaluated their allelopathic potential. Dozens of allelopathic active substances including novel compounds were also isolated from those plant species. Concept of allelopathy is very important to developed sustainable agriculture setting in organic farming. Some of the information in allelopathy have the potential for use in understanding and controlling weeds in agriculture.

Keywords: Allelopathy, Bangladesh, phytotoxicity, weed management

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1 Introduction

Although allelopathic interactions between different plant species have been aware for many years, Hans Molisch outlined the concept of allelopathy (Molisch, 1937). After his definition of allelopathy, research of allelopathy has grown and hundreds of papers have been published each year in the last decay. Allelopathy is probably involved in all aspects of natural ecosystems such as competition and succession of plant communities. Allelopathy is often associated with invasive species where it can contribute to those plants to dominate and colonize different types of ecosystems (Callaway, 2000; Cappuccino and Arnason, 2006). Much of research in allelopathy mentioned that this phenomenon can be used to control weeds and to reduce synthetic chemical input into agriculture (Islam et al., 2018b). Some allelopathic crops such as rice sorghum and wheat are selectively cultivated for weed control purpose (Sangeetha and Baskar, 2015). Allelopthic plants have used in intercropping strategies as much to halt weed invasion (Jose and Gillespie, 1998). It has also been shown that allelopathic plant residues and extracts may function as weed suppressive agents (Weston, 1996; Caamal-Maldonado et al., 2001). Allelopathic active substances isolated from allelopathic plants can be used as natural herbicides in organic farming practices or as templates to develop novel synthetic herbicides (Duke et al., 2014).

Bangladesh is located in the Indomalaya ecozone. The country has up to 6000 species of plants including 5000 flowering plants. Water bodies and wetland systems provide a habitat for many aquatic plants (Kadir, 1990; Islam and Wahab, 2005). The country having optical growing conditions over year-round, a multitude of plants are in competition and have adapted in order to get necessary nutrients as well as water and light for survival (Chengxu et al., 2011). There may be many plant species which possesses allelopathy due to the advantages it offers in such a highly competitive environment. Therefore, it is worth to study allelopathy of plants in Bangladesh. This review provides a short overview of current status of allelopathic research on plants grown in Bangladesh

2 Allelopathic potential of available plants in Bangladesh

Two hundred fifty-two plant samples from 70 families collected in Bangladesh were evaluated their allelopathic potential by the sandwich bioassay. Thirty-one percent of plants showed significant allelopathic potential on lettuce radicle elongation. Among the species, *Couroupita guianensis* (Lecythidaceae), *Phyllanthus emblica* (Phyllanthaceae) and *Acacia concinna* (Fabaceae) showed the highest inhibition on lettuce radicle elongation (Begum et al., 2019). The allelopathic potential of aqueous extracts of 55 medicinal plant species from 32 families grown in Bangladesh were also examined against the seedling growth of *Raphanus sativus* by simple Petri dish bioassay. *Citrus aurantifolia* (Rotaceae), *Moringa oleifera* (Moringaceae), *Annona muricata* (Annonaceae), *Aegle marmelos* (Rutaceae), *Cinnamomum tamala* (Lauraceae) and *Azadirachta indica* (Meliaceae) showed high allelopathic potential among those plant species (Islam et al., 2018a). Some plant species were overlapped with above two papers and shown different allelopathic potential, which may be due to different bioassay methods with different bioassay plants. In addition, the allelopathic potential of sawdust obtained from 11 tree species in Bangladesh were evaluated and sawdust of *Eucalyptus camaldulensis* showed the greatest allelopathic potential against the growth of paddy weeds (Islam et al., 2019).

3 Allelopathic active substances

3.1 Active substances in rice cultivars

The allelopathic activity of 102 Bangladesh rice (60 traditional and 42 high yielding cultivars) was determined against the seedling growth of cress (*Lepidium sativum*), lettuce (*Lactuca sativa*), barnyard grass (*Echinochloa crus-galli*) and jungle rice (*Echinochloa colona*) by 'donor-receiver bioassay' as procedure described by Kato-Noguchi et al. (2002). Among them, high yielding rice cultivar, BR17 marked the greatest inhibitory activity with an average of 39.5% growth inhibition on shoots and roots of cress, lettuce, barnyard grass and jungle rice. Traditional rice cultivars, Kartikshail marked the greatest inhibitory activity with an average of 41.8% growth inhibition on shoots and roots of barnyard grass and jungle rice (Kato-Noguchi et al., 2009; Salam and Kato-Noguchi, 2009). Therefore, BR17 had the greatest inhibitory activity against all receiver plants, and Kartikshail had the greatest inhibitory activity against *Echinochloa*.

Three allelopathic active substances, 3-hydroxy-β-ionone [Fig. 1(1)], 3-oxo-α-ionol [Fig. 1(2)] and 9-hydroxy-4-megastigmen-3-one [Fig. 1(3)] were isolated from BR17 (Salam and Kato-Noguchi, 2011; Kato-Noguchi et al., 2014a). Two allelopathic active substances, 3-hydroxy-β-ionone and 9-hydroxy-4-megastigmen-3-one were isolated from Kartikshail (Kato-Noguchi et al., 2011). The concentration required for 50% growth inhibition (defined as IC_{50}) on root growth of barnyard grass was 36.7, 16.3 and 30.2 μM for 3-hydroxy-β-ionone, 3-oxo-α-ionol and 9-hydroxy-4-megastigmen-3-one, respectively, and IC_{50} on coleoptile growth of barnyard grass was 146, 134 and 180 μM for 3-hydroxy-β-ionone, 3-oxo-α-ionol and 9-hydroxy-4-megastigmen-3-one, respectively (Salam and Kato-Noguchi, 2011). The concentrations of 3-hydroxy-β-ionone, 3-oxo-α-ionol and 9-hydroxy-4-megastigmen-3-one in BR-17 were 92.3, 75.4 and 75.4 μmol kg^{-1}, respectively (Kato-Noguchi et al., 2014a). Therefore, the rice cultivar BR17 may be potentially useful for weed management as a weed suppressing agent when incorporated into the soil or included in a rice-based cropping system.

Another trial of the evaluation of allelopathic activity of 50 Bangladeshi rice was conducted by donor-receiver bioassay against the seedling growth of cress, lettuce, radish (*Raphanus sativus*), barnyard grass and jungle rice. The highest allelopathic effect was recorded by variety Boterswar (Masum et al., 2016). Boterswar was also allelopathic in a greenhouse condition (Masum et al., 2019). Four allelopathic active substances, syringone [Fig. 1(4)], loliolide [Fig. 1(5)], 3β-hydroxy-5α,6α-epoxy-7-megastigmen-9-one [Fig. 1(6)] and 3-hydroxy-β-ionone [Fig. 1(1)] were isolated from variety Boterswar. IC_{50} values on root growth of barnyard grass were 27.2, 16.5, 16.0 and 26.2 μM for syringone, loliolide, 3β-hydroxy-5α,6α-epoxy-7-megastigmen-9-one and 3-hydroxy-β-ionone, respectively, IC_{50} value on shoot growth of barnyard grass were 36.0, 23.9, 25.5 and 75.5 μM for syringone, loliolide, 3β-hydroxy-5α,6α-epoxy-7-megastigmen-9-one and 3-hydroxy-β-ionone, respectively (Masum, 2018).

3.2 Active substances in paddy weeds

Paspalum commersonii (Poaceae) is widely distributed in South Africa, Myanmar, Bangladesh, Indonesia and India (Galinato, 1999). It often appears in rice fields as a competitive weed and is difficult to manage. Its strong competitive nature indicates the possibility of an allelopathic potential of *P. commersonii*.

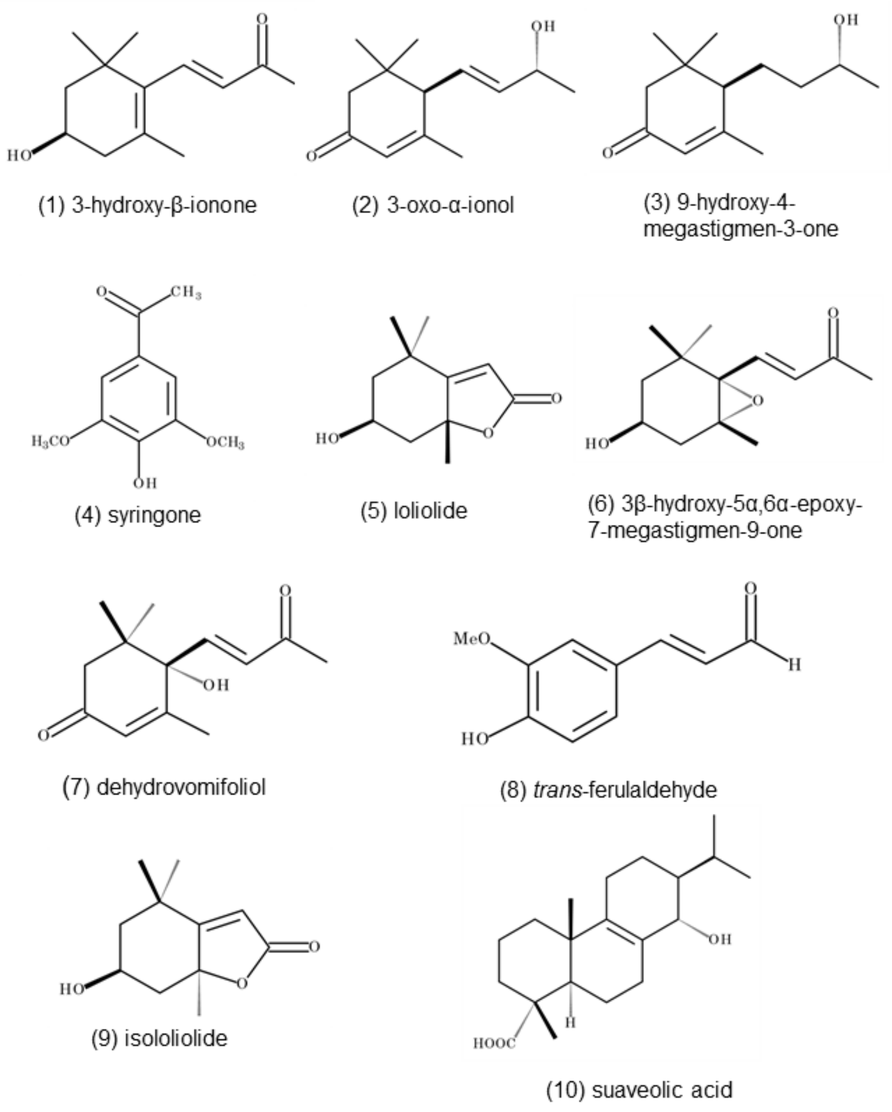
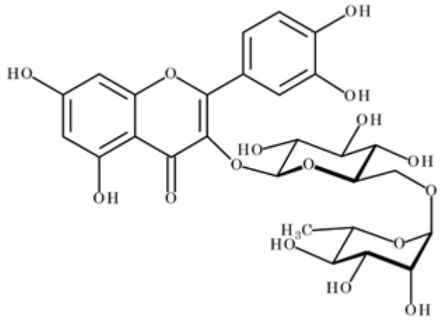


Figure 1. Chemical structures of some allelochemicals (1–10)

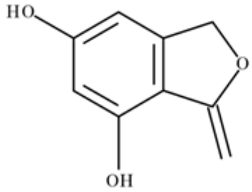
Aqueous methanol extracts of *P. commersonii* showed concentration-dependent inhibitory activity on the seedling growth of cress, alfalfa (*Medicago sativa*), rapeseed (*Brassica napus*), lettuce, barnyard grass, foxtail fescue (*Vulpia myuros*), Italian ryegrass (*Lolium multiflorum*), and timothy (*Phleum pretense*). Two allelopathic active substances were isolated and determined as dehydrovomifoliol [Fig. 1(7)] and loliolide [Fig. 1(5)]. Dehydrovomifoliol and loliolide inhibited the shoot and root growth of cress at concentrations greater than 3 mM and 0.03 mM, respectively (Zaman et al., 2018a).

Eleocharis atropurpurea (Cyperaceae), is a small, annual tufted weed widely distributed in tropical, subtropical and temperate regions (Mishra et al., 2017). *E. atropurpurea* grows abundantly in river beds, marshes and rice fields (Huda et al., 2017). The competitive behavior of this species suggests the species is allelopathic. The aqueous methanol extracts of *E. atropurpurea* inhibited the seedling growth of cress, alfalfa, Italian ryegrass and timothy. The extracts was purified and one allelopathic active substance, trans-ferulaldehyde [Fig. 1(8)] was isolated. IC_{50} values of trans-ferulaldehyde on the growth of cress and barnyard grass were in the range of 0.73 to 3.68 mM. The growth inhibitory effects suggest that trans-ferulaldehyde may be responsible for the inhibitory effects of *E. atropurpurea* (Zaman et al., 2018b).

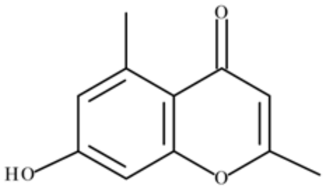
Marsilea crenata is an aquatic perennial fern prevalent in rice fields having shallow water in South-East Asia and Australia (Nagalingum et al., 2007). An aqueous methanol extracts of *M. crenata* showed the inhibition on the seedling growth of cress, lettuce, alfalfa, barnyard grass, Italian ryegrass and foxtail fescue. The extract was purified by several chromatographic steps and two allelopathic active substances



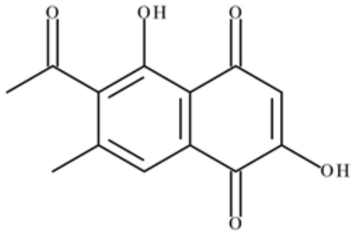
(11) rutin



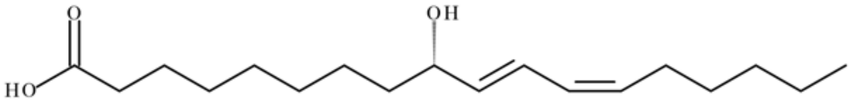
(12) 5,7-dihydroxyphthalide



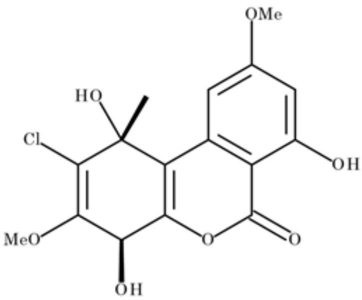
(13) altechromone A



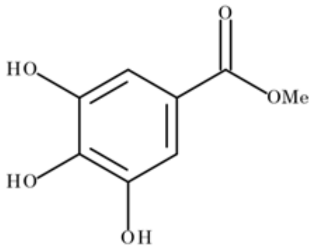
(14) 2-methoxystypandrone



(15) (9S,10E,12Z)-9-hydroxyoctadeca-10,12-dienoic acid



(16) rhizopycnin A



(17) methyl gallate

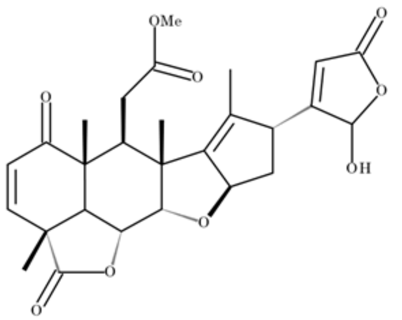
Figure 2. Chemical structures of some allelochemicals (11–17)

were isolated and identified by spectroscopic analysis as loliolide [Fig. 1(5)] and isololiolide [Fig. 1(9)]. IC_{50} values on the growth of cress and barnyard grass seedlings ranged from 32.1 to 128.5 μM for loliolide, from 37.0 to 176.2 μM for isololiolide (Islam et al., 2017c). These results suggest these compounds may be responsible for allelopathic property of *M. crenata*.

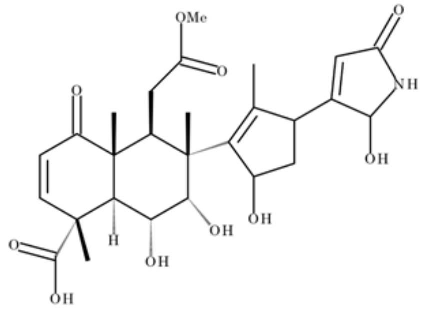
3.3 Active substances in invasive plants

Biological invasion are considered as one of the major threat for biodiversity worldwide as they are responsible for the extinction of species. The invasive plants have intrinsic characteristics and allelopathic potential was thought to be one of them. Allelopathy contributes to plant ability to takeover and colonize different types of ecosystems (Callaway, 2000; Cappuccino and Arnason, 2006; Rashid et al., 2010a,b). Allelopathic potential of the invasive plant *Hyptis suaveolens* (Lamiaceae) was evaluated and a potent allelopathic active substance, suaveolic acid [Fig. 1(10)] was isolated. Suaveolic acid inhibited the shoot growth of cress, lettuce, Italian ryegrass and barnyard grass at concentrations greater than 30 μM (Islam et al., 2014a). The finding suggests that suaveolic acid may be involved in invasive trait of *H. suaveolens*.

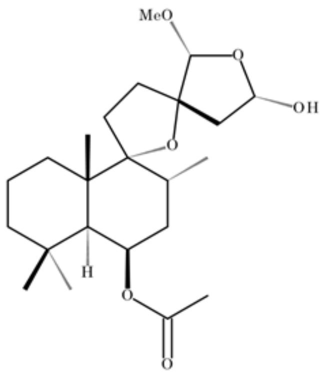
Cassia alata (Caesalpiniaceae) is a large perennial shrub, native to tropical America. The plant is invasive and now naturalized in a wide range of habitats in the tropics such as Bangladesh, Indonesia, Africa,



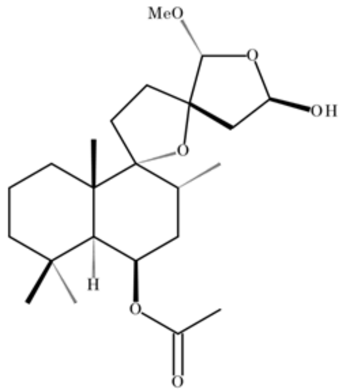
(18) nimbolide B



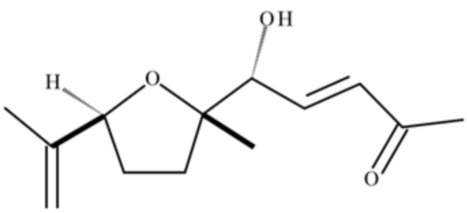
(19) nimbic acid B



(20) (*rel* 5*S*,6*R*,8*R*,9*R*,10*S*,13*S*,15*S*,16*R*)-6-acetoxy-9,13;15,16-diepoxy-15-hydroxy-16-methoxylabdane



(21) (*rel* 5*S*,6*R*,8*R*,9*R*,10*S*,13*S*,15*R*,16*R*)-6-acetoxy-9,13;15,16-diepoxy-15-hydroxy-16-methoxylabdane



(22) garcienone

Figure 3. Chemical structures of some allelochemicals (18–22)

Philippines and Jamaica (Awal et al., 2004). The extracts of *C. alata* inhibited the growth of alfalfa, cress, lettuce, rapeseed, barnyard grass, foxtail fescue, Italian ryegrass and timothy. The extracts was purified and two allelopathic active substances were isolated and characterized as rutin [Fig. 2(11)] and syringone [Fig. 1(4)]. At the concentration of 1 mM, rutin and syringone inhibited the seedling growth of cress and foxtail fescue by 4.4-34.1% and 23.5-39.1% that of control seedlings, respectively (Das et al., 2019). The two identified allelopathic active substances may be responsible for its growth inhibitory properties of *C. alata*.

Rumex maritimus (Polygonaceae) grows on the banks of water reservoirs, lakes, rivers and ponds. This plants is invasive and also found in Bangladesh, North India and the temperate Himalayas (Chopra et al., 2002). The extracts of *R. maritimus* inhibited the seedling growth of cress, alfalfa, rapeseed, barnyard grass, foxtail fescue, Italian ryegrass and timothy and three allolopathic active substances were isolated and characterized as 5,7-dihydroxyphthalide [Fig. 2(12)], altechromone A [Fig. 2(13)] and 2-methoxystypandrone [Fig. 2(14)]. IC_{50} values of 5,7-dihydroxyphthalide on cress shoot and root growth were 1.73 and 2.48 mM, respectively. IC_{50} values of altechromone A on those were 1.4 and 0.7 mM, respectively and IC_{50} values of 2-methoxystypandrone on those were 5.8 and 11.8 μM, respectively (Islam et al., 2017a,b). Therefore 2-methoxystypandrone is the most active among those three compounds. Considering allelopathic activity, those compounds may contribute to the allelopathic property of *R. maritimus*.

Chrysopogon aciculatus (Poaceae) is a creeping, vigorous, perennial weed and considered as an invasive species, but some cultures use it for medicinal purposes (Galinato, 1999). The species is widely found throughout the South-East Asian subcontinent, China, Philippines, Indonesia, Australia, Central and Western Africa, Europe, and the Pacific Islands (Chowdhury et al., 2016). The allelopathic potential of *C. aciculatus* was evaluated and two allelopthic active substances, (9S,10E,12Z)-9-hydroxyoctadeca-10,12-dienoic acid [Fig. 2(15)] and rhizopycnin A [Fig. 2(16)], were isolated. (9S,10E,12Z)-9-hydroxyoctadeca-10,12-dienoic acid inhibited the cress roots and hypocotyls at concentrations greater than 1.0 and 0.3 mM, respectively, and rhizopycnin A inhibited those at concentration greater than 1.0 mM (Islam et al., 2019).

3.4 Active substance in in mango

Mango (*Mangifera indica*), originating in Asian Indo-Burmese region, belongs to the Anacardiaceae family, and is widely distributed throughout the tropical and sub-tropical regions as one of the major edible economic fruit plants (Jahurul et al., 2015). Mango fruits have also been used as a herb in the ayurvedic and traditional medical treatments for a wide range of remedies over 4000 years (Shah et al., 2010). The allelopathic activity of the extracts of mango leaves was determined against the growth of cress, radish, rapeseed, foxtail fescue and crabgrass (*Digitaria sanguinalis*). The extracts inhibited all seedling growth and the inhibitory effects increased with the increasing extract concentration, suggesting that mango leaves may contain allelopathic substances (Khan et al., 2013). The extract was then purified by several chromatographic runs through a bioassay-directed fractionation, and an allelopathic active substance was isolated and identified by spectral data as methyl gallate [Fig. 2(17)]. IC_{50} values of methyl gallate on cress roots and shoots were 3.9 and 3.3 mM, respectively, and those on foxtail fescue roots and shoots were 1.5 and 9.5 mM, respectively (Suzuki et al., 2016). Therefore, mango is allelopathic and can be used this property for sustainable agriculture setting in organic farming.

4 Novel allelopathic active substances

Neem (*Azadirachta indica*) belongs to Meliaceas family and grows in Indian subcontinent and Southeast Asia. The species has long history as a traditional medicine for hose-hold remedies. Farmers also used traditionally various parts of the plants to control insects, pests in stored crop and livestock diseases (Brahmachari, 2004; Ogbuewu et al., 2011). Neem leaves have strong alleopathic activity against sevaral plant species including weed species in greenhouse and laboratory conditions (Salam and Kato-Noguchi, 2010; Rickli et al., 2011). Two novel allelopathic active substances, nimbolide B [Fig. 3(18)] and nimbic acid B [Fig. 3(19)] in the leaves were isolated. Nimbolide B inhibited the growth of cress and barnyard grass at concentrations greater than 0.1 - 3.0 μM, and nimbic acid B inhibited the growth of cress and *E. crus-galli* at concentrations greater than 0.3 - 1.0 μM (Kato-Noguchi et al., 2014b).

Leucas aspera belonging to Lamiaceae family grows as a competitive weed in high land crop fields, homesteads, fallow lands, and along the roadsides of both tropical and temperate Asia, and Africa. The plant is well-known to traditional healers due to its anti-oxidant, analgesic-antipyretic, anti-rheumatic, anti-inflammatory, anti-bacterial, anti-fungal, anti-venom, larvicidal and many other medicinal properties Shah et al. (2010). Allelopathic activity of the extracts of the species was recorded (Roy et al., 2006; Islam and Kato-Noguchi, 2012; Khan et al., 2013) and two novel labdane type diterpenes were isolated. Those compounds were characterized as (rel 5S,6R,8R,9R,10S,13S,15S,16R)-6-acetoxy-9,13;15,16-diepoxy-15-hydroxy-16-methoxylabdane [Fig. 3(20)] and (rel 5S,6R,8R,9R,10S,13S,15R,16R)-6-acetoxy-9,13;15,16-diepoxy-15-hydroxy-16-methoxylabdane [Fig. 3(21)]. The mixture of these compounds inhibit the germination and seedling growth of cress and barnyard grass at concentrations greater than 30 and 3 μM, respectively. IC_{50} value on the growth of cress and barnyard grass ranged between 31 and 80 μM, respectively (Islam et al., 2014b).

Garcinia xanthochymus is a medium-sized tree belonging to the family Clusiaceae. It is distributed in Southeast Asia including Bangladesh, India, China and Myanmar (Joseph et al., 2016), and has been widely used in folk medicine (Nguyen et al., 2017). The allelopathic activity against barnyard grass, foxtail fescue, alfalfa and cress were found and novel compound garcienone [Fig. 3(22)] was isolated. This compounds inhibited the growth of cress at a concentration of 10 μM. IC_{50} values on the growth of cress roots and shoots were 120.5 and 156.3 μM, respectively (Rob et al., 2019).

5 Conclusions

Plant diversity in Bangladesh is large due to its climate and location. Hundreds of plant species including about 150 rice cultivars in Bangladesh were evaluated their allelopathic potential and some of them shown strong allelopathic potential. Dozens of allelopathic active substances including novel compounds were also isolated from those plant species. Much of research in allelopathy mentioned that allelopathy can be used to control weeds and to reduce synthetic chemical input into agriculture. Allelopthic plants can be used in intercropping strategies, and as mulches and soil additives to inhibit weed germination and growth. Another aspect of utilizing allelopathic plants for advantage in agricultural setting focus more on the identification of specific compounds that convey the herbicidal activity. Those compounds isolated from allelopathic plants can either be developed as natural herbicide or used for templates to further develop novel synthetic herbicides. Several important papers about allelopathy and allelopathic active substances in plants grown in Bangladesh have published in the last decay. However, considering large plant diversity in Bangladesh, we have only discovered a small fraction of the information and the knowledge need to be accumulation.

Conflict of Interest

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

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