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Review Article

Rice Ecosystem, Allelopathy and Environment – A Review

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Abstract

Allelopathy is an important factor which contributes in determining distribution of species and their abundance within communities. Plant-plant interference is the combined effect of allelopathy, resource competition, and many other factors. Weed infestation is a major problem limiting the growth and yield of rice. Synthetic herbicide has been used for over 50 years as the prime source of weed control. The repeated use of herbicides in rice has already led to the evolution of resistance in some weed species. The conventional synthetic herbicides are becoming less effective against the resistant weed biotypes. Due to increase in the number of herbicide-resistant weeds and environmental concerns in the use of synthetic herbicides, allelopathy has been gaining preference as one of the considerable efforts in designing alternative weed management strategies. Modern ecotoxicologists and allelopathy researchers have been trying to identify allelochemicals to use as biodegradable pesticide. Two allelochemicals have been discovered, namely *hexanedioic acid dioctyl ester and di-n-octyl phthalate* which can be used as biopesticide. However, still there is enough scope to conduct such research that will contribute to protect our environment as well as increase food safety.

Key words: **Allelopathy, rice eco-system, allelochemical, environment**

1. Introduction

Rice is the main food crop and primary source of food for more than half of the world's population. More than 90% of the world's rice is grown and consumed in Asia where 60% of the earth's people live. Rice accounts for 30-75% of the calories consumed by more than 3 billion Asians. It is planted on about 154 million hectares annually or on about 11% of the world's cultivated land. According to United Nations (UN) estimation, the world population will grow from 6 billion in 2000 to 8 billion in 2030. Therefore, 40% more rice is to be produced by 2030 to satisfy the growing demand without affecting the resource base adversely (Khush, 2005).

Weed infestation is a major problem limiting the growth and yield of rice (Bhatt and Tewari, 2006). In rice, the loss of yield due to weed infestation is greater than the combined yield losses caused by insect pests and diseases (Isley, 1960). In Asia, yield losses due to uncontrolled weed growth in direct seeded lowland paddy was 45-75%, and for transplanted lowland paddy approximately 50% (Johnson, 1996). Weed infestation causes a 10-35% reduction in grain yield in Malaysia (Karim *et al.,* 2004)**.** Nearly 12% of the total loss of crop yields has been attributed to the weeds alone (Anaya, 1999). Weed plants may affect the growth of crop plants either by competition for nutrients, water, space and light (Zimdahl, 1980) or by allelopathy

(Rice, 1984). In the field, both allelopathy and competition usually act simultaneously.

In rice cultivation control of weeds is one of the important means of increasing crop yield. In all rice ecosystems, herbicides have become one of the most important components in weed control. There may be two reasons for increased use of herbicides: the first being the widespread adoption of high-yielding varieties which created economic incentives for farmers to reduce weed infestation; and the second is the availability of cheaper herbicides, indicating that the cost of weed control by herbicides in wet-seeded rice is less than one-fifth of the cost of a single hand-weeding (Moody, 1991). But the repeated use of herbicides in rice to control weed has already led to the evolution of resistance in some weed species to several herbicides in several countries (Watanabe *et al.,* 1997). The conventional synthetic herbicides are becoming less and less effective against the resistant weed biotypes. Thirty weed species associated with rice have been evolved as resistance to herbicides globally, including the most widely used compounds such as propanil, 2, 4-D and some of the sulfonylureas (Valverde *et al.,* 2000). Herbicide-resistant weeds pose the greatest threat to farmers when there are few or no other alternatives to control them (Heap, 2011). Due to increase in the number of herbicide-resistant weeds and environmental concerns in the use of synthetic herbicides, allelopathy has been gaining preference as one of the considerable efforts in designing alternative weed management strategies.

2. Allelopathy and agriculture

Weeds interfere crop growth and reduce yields, deteriorate crop quality, clog waterways and cause health problems; with eradication costs being massive (Singh *et al.,* 2003). About 240 weeds have been reported to have allelopathic potential (Qasem and Foy, 2001), although many of these species have been tested with unrealistic bioassays (Inderjit and Keating, 1999). On the other hand, allelopathic crops that are able to chemically interfere with weed growth have also been identified, such as *Secale cereale* (rye) (Haramoto and Gallandt, 2004), *Triticum aestivum* (wheat) (Labbafi *et al.,* 2010), *Oryza sativa* (rice) (Fang *et al.,* 2013), *Helianthus annus* (sunflower) (Nikneshan *et al.,* 2011) and *Glycine max* (Soyabean) (Mahmoodzadeh and Mahmoodzadeh, 2013). In addition to beneficial chemical interference of crops with weed growth, there is potential for the advantageous use of allelopathy for practices such as crop rotation, cover and smothers crops and retention of crop residues (Singh *et al.,* 2003).

According to Duke *et al.* (2002), two approaches for utilization of allelopathy in crops to increase weed suppression are possible: a) to enhance the existing allelopathic potential of a particular crop and b) to introduce allelopathic potential through the insertion of foreign genes encoding for allelochemicals. This can be achieved through employing conventional breeding as well as genetic modification techniques. With increased environmental awareness and public pressure, less detrimental means of weed control are continually being sought. One such approach is to consider allelochemicals as a new source of herbicides. This approach may be beneficial as natural plant products which have advantage over synthetic herbicides. The benefits are many: a) allelochemicals often possess complex structures and exhibit structural diversity, making them valuable lead compounds, b) the compounds have molecular weight with little or no halogens or heavy atoms, c) allelochemicals have little environmental impacts as they degrade rapidly in the environment, and d) allelochemicals have novel target sites very often different to those of synthetics (Duke *et al.,* 2002; Singh *et al.,* 2003).

3. Weed allelopathy

A total of 240 weeds have been reported to have allelopathic potential (Qasem and Foy, 2001). Since weeds are a major cause of yield losses, the aggressive growth habits of some of the most tenacious species have come in for scrutiny.

Putnam and Weston (1986) listed 90 weed species that showed allelopathic potential. It has been reported that some of the world's worst weeds contain allelochemicals including parthenium *(Parthenium hysterophorus)* (Nath, 1988), quackgrass *[Elytrigia repens* (L.) *(*Putnam and Weston, 1986*)*, Johnsongrass *(Sorghum halepense* (Abdul- Wahab and Rice, 1967), Canada thistle (*Cirsium arvense)* (Stachon and Zimdahl, 1980) and giant foxtail *(Setaria faberi) (*Bell and Koeppe, 1972*)*. The most investigations on weeds have tried field-based evidence with a search for allelochemicals. *Parthenium hysterophorus*, a tropical weed endemic to America, has done great damage to human, livestock and crops since arriving as an exotic to the Indian landscape and other places. Numerous reports of the last two decades documented the phytotoxicity of its living and decomposing tissue, leachates, and root exudates (Forzwa and Karim, 2009). Recently, Ismail and Siddique (2012a, 2010(a), 2010(b); Siddique and Ismail (2010, 2009) reported that common rice field weeds i.e *Fimbristylis miliacea*, *Cyperus iria*, *Echinochloa colona* and *Sphenoclea zeylanica* showed growth inhibitory effects on the rice plants. Four common weeds grown in rice fields showed their allelopathic potential on paddy rice of Tarom variety in Pakistan (Alamdari and Deokule, 2009) (Table 1). Due to genetic variation, different rice verities responded differently (Table 2 and Figure 1) to the phytotoxic effect of *Cyperus iria* (Ismail and Siddique, 2011).

Table 1. Effect of whole plant leachates of studied weeds on growth parameters of paddy rice of Tarom variety (Alamdari and Deokule, 2009)

Whole plant leachates of studied weeds	Growth parameters		
	Total number of tillers pot^{-1}	Plant height (cm)	Elongation of flag leaf (cm)
Cyperus difformis	17.11 ± 1.57*a*	103.76 ± 13.67*a*	21.89 ± 3.04*a*
Echinochloa crusgalli	14.45 ± 0.69*a*	97.29 ± 5.55*a*	22.22 ± 0.75*a*
Paspalum paspaloides	15.56 ± 1.17*a*	99.80 ± 9.20*a*	25.41 ± 2.58*a*
Sagittaria trifolia	16.44 ± 1.17*a*	94.75 ± 5.75*a*	22.36 ± 1.55*a*
Control	16.44 ± 1.17*a*	100.72 ± 3.02*a*	24.23 ± 2.85*a*
Mean	16.02 ± 1.66	99.26 ± 7.70	23.22 ± 2.42

*Mean (±) Standard deviation and groups based on Duncan's Univariate comparison with 95% confidence intervals (*n=3*).

Table 2. Effect of the debris of *C. iria,* on plant height, seedling fresh and dry weight (% of control) of 5 rice varieties (Ismail and Siddique, 2011)

Debris concentration								
Rice	Control	Quarter	Half	Full	Control	Quarter	Half	Full
varieties	Plant height				Fresh weight			
MR211	100.0^{a}	81.8^{b}	72.8^{b}	69.7^{b}	100.0a	74.7^{b}	73.5^{b}	67.5^{b}
MRQ74	100.0^{a}	85.0^{b}	71.7^{c}	67.0^{d}	100.0a	73.1^{b}	64.6^{b}	66.9^{b}
MR220	100.0^{a}	80.8^{b}	74.4^{b}	73.5^{b}	100.0a	72.9^{b}	66.0^{b}	63.6^{b}
MR84	100.0^{a}	68.1^{b}	66.8^{b}	66.8^{b}	100.0a	70.4^{b}	62.4^{bc}	57.1^{c}
MR232	100.0^{a}	65.0^{b}	65.2^{b}	58.9^{c}	100.0a	59.1^{b}	53.1^{b}	47.0^{c}

Means within rows followed by same letter are not significantly different ($p>0.05$, $LSD_{0.05)}$

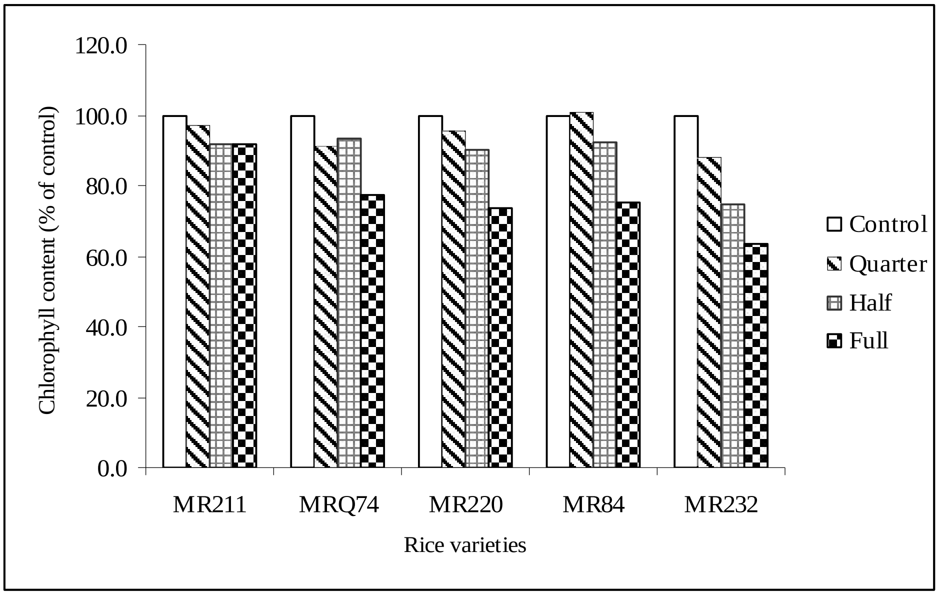

Fig. 1. Inhibitory effect of the debris of *C. iria* on leaf chlorophyll content (% of control) of five rice varieties (Ismail and Siddique, 2011)

4. Allelopathy in rice

To establish an alternative strategy for weed management in rice, the phenomenon allelopathy has been a subject of continued research for a long time (Olofsdotter, .2001; Takeuchi *et al.*, 2001) and already a large number of rice varieties have been found to suppress several weed species when grown together under field and laboratory condition (Dilday *et al.*, 1998; Olofsdotter *et al.*, 1999; Azmi *et al.*, 2000). The first observation of rice was made in field examination in Arkansas, USA where about 191 of 5,000 rice accessions inhibited the growth of ducksalad weed (*Heteranthera limosa*) (Dilday *et al.*, 1989) which led to a further large screening program. USA-ARS have screened more than 16,000 rice accessions from 99 countries and 412 rice accessions have shown the allelopathic potentiality against *Ammonia coceinea* (Dilday *et al.*, 1998). Dilday *et al.* (1998) evaluated the phytotoxic effects of 12,000 and 5000 rice accessions against ducksalad (*Heteranthera limosa*) and red stem (*Spinacia oleracea*)**,** respectively. Several field screening was made in different countries such as Egypt, Korea, Japan, India, Thailand, Malaysia and United States (Dilday *et al.*, 1998). In Egypt, more than 40 out of 1000 (were screened) rice varieties showed inhibitory activity with *Echinochloa crusgalli* and *Cyperus difformis* (Hassan *et al.*, 1998) and suggested that genetic variations is the main factor to environment. Salam and Noguchi (2009) reported that the rice variety BR17 is the most allelopathic among 102 Bangladesh rice cultivars. Water extract of rice in different concentrations showed different degree of allelopathic inhibition on wheat, radish and lettuce (Tareak, 2010) (Table 3).

Table 3. Effect of six rice straw extract concentrations on seedling root growth of four plant species/cultivars over time (Tareak, 2010)

Conc. (g 500 mL^{-1} H_2O)	Wheat (*Triticum aestivum*)						Radish *(Raphanus sativus)*			Lettuce *(Lactuca sativa)*	
	Sakha 61			Sakha 94							
	72 h	96h	120h	72 h	96h	120h	72 h	96h	120h	120h	144h
20	51.9	61.3	67.5	35.2	31.4	23.9	45.6	34.1	33.9	23.2	5.4
30	51.9	52.1	56.5	31.5	19.6	9.2	36.8	23.5	32.7	0.0	0.0
40	37.9	52.3	59.1	25.4	17.5	12.5	0.0	23.5	35.6	0.0	0.0
50	23.8	30.5	59.7	21.9	13.2	7.1	0.0	5.8	11.0	0.0	0.0
70	14.4	31.7	47.3	19.8	13.5	7.0	0.0	6.3	11.1	0.0	0.0
Control	100	100	100	100	100	100	100	100	100	100	100
LSD 0.05	15.1	22.7	21.1	7.5	6.8	7.1	8.8	11.0	10.6	1.8	1.8

Values are expressed as a % of the control.

International Rice Research Institute (IRRI) developed a laboratory method for screening whole- plant-bioassay or allelopathic rice screening (Navarez and Olofsdotter, 1996) to eliminate the effects of competitive interference for resources between rice and test plants. Interestingly using this method, inhibitory activity of 111 rice varieties in Philippines has been shown to be inconsistent between laboratory and field trials (Olofsdotter *et al.,* 1999). However, in both laboratory screening and field experiments revealed that rice allelopathy is active in both monocot and dicot weeds (Dilday *et al.,* 1991; Fuji 1994; Olofsdotter and Navarez, 1996; Hasan *et al.*, 1998; Kim and Shin, 1998). Laboratory screening for allelopathy study in rice have also been undertaken and it has been found that there was no mark difference among rice varieties for weed species inhibition activity (Fuji, 1994; Hasan *et al.*, 1998; Azmi *et al.*, 2000) suggesting that different rice cultivars are capable to supress particular weed species.

5. Rice allelochemicals

The exploiting research for isolating and identifying rice allelochemicals has started but yet not yielded chemicals that could exert allelopathic effect (Rimando *et al.*, 2001). Several studies have been conducted by various researchers to identify allelochemical(s) from rice and to find their allelopathic potential (Chung *et al.,* 2001; Kim and Kim, 2002; Rimando *et al.*, 2001; Kong *et al.*, 2004; Seal *et al.,* 2004a). Among them Seal *et al*. (2004a) found 200 different compounds in rice root exudates which fall under three main chemical classes such as phenolics, phenylalkanoic acids and indoles. Several classes of secondary metabolites determined from the root exudates of rice like phenolics (Jung *et al.*, 2001; Kim and Kim, 2002; Rimando *et al.*, 2001; Olofsdotter *et al.*, 2002; Inderjit *et al.*, 2002; Seal *et al.*, 2004b), alkyl resocinols (Bouillant *et al.*, 1994), momilactone B (Kato-Noguchi and Ino, 2005; Kong *et al.*, 2004), amino acids (Bacillo_Jimenez *et al.*, 2003) and flavones (Kong *et al.*, 2004). Several studies focused that common putative allelochemicals found in rice are phenolic acid compounds (Chou *et al.*, 1991; Inderjit 1996; Blum, 1998) such as p-coumaric acid, p-hydrobenzoic acid, ferulic acid and vanillic acid. Nontheless, it is belived that phenolics must play an important role for rice allelopathy. So, identifying allelochemical in rice is an important issue for understanding allelopathy mechanism.

A large number of rice varieties were found to inhibit the growth of several plant species when the rice varieties were grown together with the plants under field and/or laboratory conditions (Dilday *et al.*, 1998; Hassan *et al.*, 1998; Olofsdotter *et al.*, 1999). These findings suggest that living rice may produce and release allelochemical(s) into the neighboring environment. A number of secondary metabolites, phenolic acids, phenylalkanoic acids, hydroxamic acids, fatty acids, terpenes and indoles were identified in rice extracts (Rimando and Duke, 2003). These compounds are ubiquitous in plants and some of these compounds have growth inhibitory activity against several plant species. It is not clear, however, whether these compounds are released from living rice plants into the neighboring environment, and act as allelochemicals in natural ecosystems. In addition, it was found that there was no significant correlation between the level of growth inhibitory substances in plants and their level in the root exudates (Wu *et al.*, 2001). It was found that the growth of soybean callus was inhibited by rice callus when both callus tissues were incubated together (Yang and Futsuhara, 1991). Zhang *et al*. (2005) identified potent allelopathic rice germplasm for breeding new rice varieties with allelopathic potential. Yiqing *et al*. (2005) focussed on the evaluation of allelopathic wild rice species germplasm resources for barnyardgrass control. He *et al*. (2006) detected the diethyl ether extracts from the root exudates of two rice accessions, allelopathic rice (PI312777) and non-allelopathic rice (Lemont) seedlings. The individual compounds were identified by comparing their mass spectra with those from NIST and Wiley Library of mass spectral database. Sixty-three compounds were detected in root exudates of PI312777 and 77 compounds in Lemont. The substances were terpenoids, phenols (quinones), aldehydes (ketones), heterocyclic alcohols, ethers, hydrocarbons etc. (He *et al*., 2006). Hiroshi (2008) examined the effect of husk extracts of wild rice spp. on root and shoot growth of lettuce, barnyard grass and *Eclipta thermalis* (false daisy). The results suggested that the husk extracts of *Oryza glumaepatula* contain water soluble allelochemicals that inhibit root growth of lettuce but promote shoot growth of false daisy. Ethyl acetate soluble allelochemicals that inhibit root growth of barnyard grass. Olofsdotter *et al*. (1995) described the assessment of the allelopathic potential of root exudates from rice plants during their early developmental stage and allelopathic potential of rice leaching by using Petri dish bioassay under laboratory condition.

6. Conclusions

Despite the tremendous growth in allelopathy research in recent years there are lots of areas that have yet not been studied. Isolation and identification of rice allelochemicals are important to toxicological and eco-toxicological studies before crossing between present traits and commercial germplasm. Agronomic managements of rice like date of sowing, seeding depth, standing water depth, amount and type of fertilizers, duration of dry period, density and species of weeds are to be investigated for rice based allelopathy. Using allelopathic potential, rice cultivars in crop rotation and as companion crop need to be studied. Some rice cultivars are showing residual allelopathic effects on weed emergence as they contain acid during their decomposition. In paddy field, many weed species are either completely inhibited or significantly reduced by rice allelopathic potential. Eeveral studies have focused that the allelopathic materials on weed species are selective. Therefore, sensitive weeds are to be evaluated for their seed moisture content, growing habit, survival capability and extend of competitive ability against rice for natural weed management. So, to understand rice-weed chemical interaction, detail researches are needed with a long term vision.

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