Rice straw as an allelopathic agent for controlling weeds

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Summary A laboratory bioassay using water extract was conducted to investigate the allelopathic potential of rice straw on certain plant species including two varieties of wheat, radish and lettuce. A wide range of rice straw weights (20, 30, 40, 50, 70 g) was used for the extraction and testing. Generally, seed germination (%) was unaffected by rice straw extracts. In contrast, seedling growth (root and shoot lengths) was affected by the extracts, with reductions being measured. Root growth was more sensitive than shoot growth and the effect increased with concentration. Re-investigating rice straw at the most effective concentration (50 g) in comparison with leaf, root and stem of the same source showed great inhibitory effects on the test seeds although varietal differences were also evident. These results show the existence of several bioactive compounds in rice straw. In the future, these compounds might serve as a source of natural herbicides.

Keywords Weeds, allelopathy, herbicides, inhibition, rice straw.

INTRODUCTION

Weeds are one of the most deep-rooted problems facing agriculture throughout the world. Even with the intensive use of synthetic herbicides, weeds cause 10–30% crop losses, while without weed control crop losses could be 45–95%, depending on ecological and climatic conditions (Ampong-Nyarko and De Datta 1991, Moody 1991). Weed management is, therefore, a key factor of most agricultural system. Synthetic herbicides have been a weed control solution for many years, but their hazards against environment and public health have raised questions about our reliance on such chemicals. Allelopathy, the chemical interactions between plants, is one candidate to replace synthetic herbicides (Xuan *et al.* 2005).

A significant amount of recent research has confirmed the possibility that rice and its debris release compounds with phytotoxic activity into the environment. Allelopathy research in rice has involved all parts of the plant including leaf, root, stem and even seed hulls (Chung *et al.* 2003). The research included live as well as dead plants (Jung *et al.* 2004, Kim *et al.* 2005). Studies have also included all stages of growth from seedling to flowering and even after harvest (Kato-Noguchi 2004). Although phenolic compounds (e.g. *p*-salicylic, *p*-coumaric, vanillic, syringic, ferulic, *p*-hydroxybenzoic, and mandelic acids) are often mentioned as the dominant allelochemicals (Chou 1980, Chung *et al*. 2001), this idea has recently been criticised (Olofsdotter *et al.* 2002). A potent allelochemical, for example, has recently isolated from root exudates of rice seedlings cv. Koshihikari and identified as momilactone B (Kato-Noguchi *et al.* 2002). As a growth inhibitor, Kato-Noguchi and Ino (2005) illustrated that momilactone B plays an important role in rice allelopathy activity, although its function is still unknown. Steroids like ergosterol peroxide and 7-oxo-stigmasterol have also been isolated as effective phytotoxins from rice (Macías *et al*. 2006).

The aim of the present study was to study the potential biocidal effect of rice straw extract as a putative source for controlling weeds.

MATERIALS AND METHODS

Effect of rice straw extract on seed germination and seedling development of some plant species The allelopathic effect of rice straw was studied *in vitro* using different concentrations of aqueous extracts. Rice straw (cv. Giza 101) was collected after harvesting and allowed to dry for an additional time (5 days) under room temperature (28–30°C). The straw was chopped using scissors into 0.5–1 cm pieces and extracted at different concentrations (20, 30, 40, 50 and 70 g) overnight using distilled water (500 mL) at room conditions. The aqueous extracts were filtered through Whatman filtered paper No.1 to remove excess debris and centrifuged for 15 minutes at 4000 rpm to remove all particulate matter. The clear extracts were used freshly in bioassay test.

Seeds of radish (*Raphanus sativus* L.), lettuce (*Lactuca sativa* L.) and two of wheat cultivars (*Triticum aestivum* L., Sakha 61 and Sakha 94) were examined for their response. The species were particularly selected for their sensitivity (Lydon and Duke 1989) and because they are typically sown into rice residues.

Twenty uniform seeds for each species were placed in 7 cm diameter glass Petri dishes on filter paper (Whatman No. 1) wetted with 2–3 mL of the extracts based on seeds size. Two millilitres was used for lettuce and 2.5 and 3 mL were used for radish and wheat, successively. The seeds were diametrically arranged into Petri dishes to minimise competition as far as possible. Distilled water was used as a control. The experiment was performed in triplicate using randomise complete design. The seeds were allowed to germinate in dark under lab conditions with an average temperature 19°C for estimated periods five days for wheat and radish and six days for lettuce. Germination was recorded daily after an interval 48 h. The seeds were considered to be germinated when the emerging radical elongated to more than 1 mm. Seedling root and shoot growth (cm) were estimated at 72, 96 and 120 h for wheat and radish and at 120 and 144 h for lettuce to estimate elongation rate. Preliminary trials were conducted to determine the average germination rate for all species and hence the most appropriate time for measuring radical and shoot lengths.

The effect of different parts of rice straw (leaf, stem and root) was also examined for their activity against test species. Root (50 g) was collected and treated as previously described, in parallel with leaf, stem and intact straw. Three replicates were used for each treatment.

Statistical analysis All data were statistically analysed by ANOVA, and treatment means were compared using LSD at P = 0.05.

RESULTS

The effect of rice straw extracts on lettuce seed germination is shown in Table 1. There were significant differences in germination between different concentrations of rice straw extract. Germination of wheat and radish seeds was unaffected by rice straw extracts (data not shown).

Seedling root (Table 2) and shoot growth (data not shown) was more affected by the extracts than seed germination. Generally, the percentage growth reduction increased with the concentration, increased over time and root growth was more sensitive than shoot growth. There were differences between the species: lettuce was the most sensitive overall, followed by wheat (cv. Sakha 94) and radish. It was estimated that there would be entire growth failure for lettuce at extract concentrations of 30–70 g.

The effect of different parts of rice straw including root as well as intact plants on seedling development of wheat (cv. Sakha 94) and radish is given in Table 3. Seedling root and shoot growth was substantially reduced by the different extracts. Root growth was more sensitive than shoot growth, and leaf extract was the most effective overall.

Table 1. Effect of six rice straw extract concentrations on cumulative germination of lettuce. Values are expressed as a % of the control.

Conc.	Lettuce (*Lactuca sativa*)			
(g 500 mL^{-1} H_2O)	48 h	72 h	96 h	120 h
20	60.8	80.2	101.3	101.3
30	11.8	15.1	26.3	26.3
40	0.0	0.0	2.2	2.2
50	0.0	0.0	2.2	2.2
70	0.0	0.0	0.0	0.0
Control	100	100	100	100
LSD 0.05	9.6	13.4	14.0	14.0

DISCUSSION

This study was carried out with a preliminary objective of determining rice straw toxicity based on testing different quantities of the residue and then using the most effective concentration in more detailed studies.

The results reported here clearly indicated that rice straw was very toxic at all levels investigated, with significant reduction in seedling root and shoot growth. The allelopathic activity of rice plants and their residues has previously been reported. For example, Olofsdotter *et al.* (1999) referred to the possibility that rice plants exhibit allelopathic activity during their investigation of 111 rice cultivars under field conditions. Studies indicated that allelochemicals in rice can release throughout the entire life of the plant through root secretion, leaching or even residue decomposition (Kato-Noguchi and Ino 2005, El-Shahawy *et al*. 2006). Roots, stems and leaves are all involved in rice allelopathy (Chung *et al*. 2003). Rice straw, the most problematic issue in countries like Egypt, was confirmed as containing phytotoxic activity. Phenolic acids, e.g. *p*-hydroxybenzoic, vanillic, *p*-coumaric and ferulic acids, were identified as the main allelochemicals in rice and its residues (Chung *et al*. 2001), although this idea has recently been criticised (Olofsdotter *et al.* 2002).

Significant differences in seed sensitivity were also evident. Lettuce, for example, was the most sensitive overall for both germination and seedling root and shoot growth. The wheat cultivar Sakha 94 was more sensitive than Sakha 61. Radish was much closer to wheat (i.e. Sakha 61) than lettuce. Thus, Sakha 61 should follow rice in a crop rotation rather than having a Sakha 94/rice combination. The allelopathic compounds in rice may be highly selective and/or there may be varying seed tolerance to allelopathic compounds. Several related and unrelated studies have

Table 2. Effect of six rice straw extract concentrations on seedling root growth of four plant species/cultivars over time. Values are expressed as a % of the control.

Conc. ($g\ 500\ mL^{-1}\ H_2O$)	Wheat (*Triticum aestivum*) Sakha 61 72 h	96 h	120 h	Wheat Sakha 94 72 h	96 h	120 h	Radish (*Raphanus sativus*) 72 h	96 h	120 h	Lettuce (*Lactuca sativa*) 120 h	144 h
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

Table 3. Effect of extracts ($50\ g\ 500\ mL^{-1}\ H_2O$) from different parts of the rice plant on seedling growth of wheat (cv. Sakha 94) and radish over time. Values are expressed as a % of the control.

Rice parts	Wheat (*Triticum aestivum* cv. Sakha 94) Root growth 72 h	96 h	120 h	Wheat Shoot growth 72 h	96 h	120 h	Radish (*Raphanus sativus*) Root growth 72 h	96 h	120 h	Radish Shoot growth 72 h	96 h	120 h
Leaf	12.3	11.3	8.0	32.23	16.7	16.1	14.2	13.6	11.1	34.8	28.7	17.7
Stem	20.7	25.3	27.0	47.56	40.2	38.8	14.0	19.9	16.8	37.2	44.6	32.6
Root	9.1	10.0	22.0	44.78	38.0	33.1	11.1	10.5	9.8	30.1	24.7	21.5
Intact straw (leaf plus stem)	23.7	24.5	24.9	42.99	36.9	33.4	23.8	18.3	15.4	47.7	38.1	30.8
Control	100	100	100	100	100	100	100	100	100	100	100	100
LSD 0.05	2.8	6.6	6.9	3.5	3.5	8.3	6.9	0.7	10.1	17.2	25.2	14.8

dealt with this point confirming that allelopathic compounds have different selectivity against test seeds. For example, Sampietro *et al.* (2005) found different phenolic acids (isolated from sugarcane) produced different activities against a wide range of cultivars and species. Similar responses have been noted by Chung *et al*. (2001) and later by Kato-Noguchi and Ino (2005) for rice extracts/allelochemicals against cress, lettuce and barnyardgrass seeds. Mattice *et al.* (2001) and Chung *et al.* (2003) during that time found barnyardgrass to have different responses to rice allelochemicals.

The results of the study also showed that leaf extract was more effective than the stem extract and even the root extract. This agreed with previous findings. Ebana *et al*. (2001), for example, reported that stem and root extracts of rice cultivars were generally less effective than leaf extract. Although leaf extracts have often been mentioned as the most effective source of allelopathic agents in the plant, this is not always the case. Chung *et al*. (2003) found different activities for rice cultivars based on test organ; the highest inhibition rate for Danganeuibangju accession was, for example, for its residues (e.g. the straw), for Dongobyeo was for leaves and for hulls in the Baek accession.

It has been suggested that rice straw might contain effective compounds to be used as natural herbicides. Further studies will be conducted on purification, identification and testing such compounds under field conditions.

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