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Sugarcane Field Residue and Root Allelopathic Impact on Weed Seed Germination

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Abstract

Allelopathy, the chemical interaction between plants, may result in the inhibition of plant growth and development, which can include compounds released from a crop that adversely impact weed species. The objective of this research was to determine the allelopathic impact of sugarcane (*Saccharum officinarum*) field residue and root water extracts on seed germination of three weed species. Red morningglory (*Ipomoea coccinea* L.), redroot pigweed (*Amaranthus retroflexus* L.), and spiny amaranth (*Amaranthus spinosus* L.)] seeds were treated with five extract concentrations (0, 12.5, 25, 50, and 100 g/L) from either sugarcane field residue or sugarcane root extracts. The field residue and roots were from sugarcane variety 'HoCP 96-540' plant cane. Germination generally decreased with increasing sugarcane field residue extract concentrations in the three weed species tested. At the highest residue concentration (100 g/L), red morningglory, redroot pigweed, and spiny amaranth germination decreased by 29%, 17.5% and 80.5%, respectively. Germination generally decreased with increasing sugarcane root extract concentrations in red morningglory and redroot pigweed, but not with spiny amaranth. The highest root concentration (100 g/L) decreased red morningglory and redroot pigweed germination by 19.5% and 18.5%, respectively. This research provides the first bioassay demonstrating that sugarcane root extracts have allelopathic activity, and specifically in respect to red morningglory and redroot pigweed germination. Future research should investigate the allelopathic compounds present in the sugarcane field residue and roots, determine if the same allelopathic compounds are present and in similar concentrations among other sugarcane varieties, and further examine which weed species may be susceptible to the allelopathic compounds present in sugarcane roots.

Keywords: allelopathy, pestiphytology, red morningglory, redroot pigweed, seed germination, spiny amaranth, sugarcane

1. Introduction

1.1 Allelopathy

Allelopathy is the biochemical interaction between plants, whether inhibiting or stimulating plant growth and development (Molisch, 1937; Rice, 1984). Many plant species, both crop and weed plants, are now known to produce compounds that when released into the environment can impact the growth and development of other plants (Rice, 1984). The general public's interest in more naturally produced crops is a positive incentive to explore the use of natural plant chemicals to either promote crop growth and production, or inhibit weed growth and development (Bowmick & Doll, 1982; Rice, 1984; Russo et al., 1997a, 1997b; Webber et al., 2015a, 2015b; 2017a, 2017b). Information gleaned from allelopathic compounds is used to produce natural herbicides and in development of synthesized herbicides which are closely related to the allelopathic compounds (Duke & Dayan, 2013; Cheema & Khaliq, 2000; Gerwick & Sparks, 2014).

Allelopathy can also adversely impact the same crop that is producing the allelopathic chemicals (autotoxicity) when an annual crop is replanted in the same field or where a perennial crop is present multiple years (Putnam,

1985; Schreiner & Reed, 1907). Examples of autotoxicity for annual crops include barley (*Hordeum vulgare* L.) (Ben-Hammouda et al., 2002), corn (*Zea mays* L.) (Almezori et al., 1999; Anderson & Cruse, 1995), rice (*Oryza sativa* L.) (Chen et al., 2008; Chou & Chiou, 1979), winter wheat (*Triticum aestivum* L.) (Wu et al., 2007; Wu et al., 2001), and sorghum (*Sorghum bicolor* L. Moench) (Ben-Hammouda et al., 1995). Sorghum produces sorgolene, an allelopathic compound that inhibits photosynthesisis similar to the commercial herbicide atrazine (Nimbal et al., 1996). Examples of perennial crops exhibiting autotoxicity include alfalfa (*Medicago sativa* L.) (Chung & Miller, 1995; Hedge & Miller, 1990), asparagus (*Asparagus officinalis* L.) (Motoki et al., 2002), and sugarcane (*Saccharum officinarum*) (Viator et al., 2006).

1.2 Sugarcane and Allelopathy

Allelopathic compounds have been detected within sugarcane leaves in several studies (De Carvalho et al., 1996; Singh et al., 2003; Viator et al., 2006). For example, Viator et al. (2006) identified benzoic acid from post-harvest sugarcane field residue, variety 'LCP 85-384'. Benzoic acid and its derivatives have been shown to be allelopathic to cotton (*Gossypium hirsutum* L.) (Lodhi et al., 1987), wheat (Lodhi et al., 1987) and ryegrass (*Lolium* spp.) (Wu et al., 2002) and dicamba, a commercial herbicide, is a benzoic acid compound. In addition, the allelopathic compounds of ferulic, vanillic and syringic acids have been isolated from sugarcane field residue leachates (Sampietro et al., 2005; Sampietro & Vattuone, 2006b). Phenolic compounds, used in commercial herbicides (i.e. bromoxynil and isonil), have been isolated from sugarcane leaves (Sampieto & Vattuone, 2006a; Takahashi et al., 2010).

Sugarcane field residue leachates reduced germination and radicle growth of the field crops oat (*Avena nuda* L.), (Viator et al., 2006), rye (*Secale cereale* L.) (Viator et al., 2006), sorghum (*Sorghum bicolor* L. Moench) (Sampietro & Vattuone, 2006b), and wheat (*Triticum aestivum* L.) (Sampietro & Vattuone, 2006b); the vegetable crops tomato (*Solanum lycopersicum* L.) (Webber et al., 2017b), Chinese kale (*Brassica oleracea* L. var. *alboglabra* Bailey) (Webber et al., 2017b), cucumber (*Cucumis sativus* L.) (Webber et al., 2017b), and radish (*Raphanus sativus* L.) (Sampietro & Vattuone, 2006b); and the weeds arrowleaf sida (*Sida rhombifolia* L.) (Sampietro et al., 2007), pigweed (*Amaranthus quitensis* L.) (Sampietro & Vattuone, 2006b), wild mustard (*Brassica campestris* L.) (Sampietro & Vattuone, 2006b), and tall morningglory (*Ipomoea purpurea* L. Roth) (Viator et al., 2006).

In addition to the sugarcane leaves, allelopathic compounds have been isolated from the leachate and breakdown of sugarcane bagasse lignocellulosic material (Rodrigues et al., 2001), but the authors are unaware of any published research documenting the allelopathic activity of sugarcane roots. Sorghum, also a monocotyledonous crop, is a notable example of allelopathic activity, producing toxic compounds not only in the leaf material but also in the roots (Moosavi et al., 2011; Rice, 1984; Weston et al., 2013; Yarnia et al., 2009). Therefore, it follows that if the sugarcane leaves and bagasse have allelopathic activity (Webber et al., 2017b), that the roots may also be allelopathic. Research was initiated to determine the allelopathic impact of sugarcane field residue and root extracts on the germination of three weed species (red morningglory, redroot pigweed, and spiny amaranth).

2. Material and Methods

2.1 Plant Material Collection

Sugarcane var. 'HoCP 96-540' (Tew et al., 2005) field residue (straw) and roots (Smith et al., 2005) were collected at the USDA, ARS, Sugarcane Research Unit, Ardoyne Farm, Schriever, LA immediately after harvesting the sugarcane in 2015 and 2016, respectively. The field residue averaged 716 g/m^2 (71.6 mt/ha) on an oven dry weight basis, which included leaves, immature nodes and growing tips. Sugarcane roots were collected from a 4 m section of recently harvested sugarcane var. 'HoCP 96-540'. The soil and debris was washed from the roots prior to further processing.

2.2 Sugarcane Extract Preparations

The sugarcane field residue and roots were dried in a forced air oven at 60 °C to a constant weight. The dried material was then ground using a Thomas-Wiley Laboratory Mill with a 2 mm sieve. The plant materials and deionized water were added to 4000 ml flasks and placed on a Lab-Line Orbit Shakers at 100 rpm for 12 h at room temperature (22 °C). The extracts were vacuum filtered using a three step process; 1) filtered through a Buchner funnel sans filter paper, 2) Buchner funnel with a VWR Qualitative, 417 filter (9.0 cm diameter), and 3) Buchner funnel with a Whatman® #2 filter (9.0 cm diameter). The samples were then diluted as needed with deionized water to produce concentrations of 100 g/L (full strength), 50 g/L (half strength), 25.0 g/L (quarter strength) and 12.5 g/L (eighth strength) extracts of sugarcane roots and sugarcane field residue (Webber et al., 2005a; 2005b; 2017b). The pH for all dilutions was adjusted to 7.0 using 1M KOH and 5% $C_2H_4O_2$ (acetic acid).

2.3 Extract Treatments of the Seeds

Red morningglory (*Ipomoea coccinea* L.) seed was collected by Eric Petrie, USDA, ARS, Sugarcane Research Unit, 5883 USDA Road, Houma, Louisiana, 70360, USA) at the USDA research farm at Houma, Louisiana. The redroot pigweed (*Amaranthus retroflexus* L.) was purchased from River Refuge Seed Company, 26366 Gap Road, Brownsville, Oregon, 97327, USA, and the spiny amaranth (*Amaranthus spinosus* L.) was collected at South Central Agricultural Research Laboratory, Lane, Oklahoma 74555. Seeds of these three weed species were surface sterilized for 1 min using a 50% bleach (6% sodium hypochlorite) 50% deionized water solution. The seeds were then rinsed with deionized water and allowed to air dry for 10 min. Twenty seeds of each plant species were placed in separate Petri plates which contained 9.0 cm Whatman® No. 2 filter papers. To each Petri plate was added 10 ml of either sugarcane field residue or root extract at each of the concentrations [0 (deionized water), 12.5, 25, 50, and 100 g/L]. The Petri plates were covered and placed in a dark incubator at 27 °C. After 7 d the Petri plates were removed and seed germination was measured. Seeds were considered germinated when the seed radicle was equal to or greater than the length of the width of the seed of the specific plant species being measured. The experimental designed included 2 sources of extracts (sugarcane field residue and roots), 5 treatment extracts (0, 12.5, 25, 50, and 100 g/L), 3 weed species (red morningglory, redroot pigweed, and spiny amaranth). The experiment was repeated twice with 5 replications in each experiment. All data were subjected to ANOVA and mean separation using LSD with P = 0.05 (SAS Inc., SAS, Ver. 9.4, Cary, NC).

3. Results and Discussion

3.1 Statistical Analysis

Statistical analysis determined that there were significant interactions among plant species (red morningglory, redroot pigweed, spiny amaranth) and extract concentration (0, 12.5, 25, 50, and 100 g/L) (Table 1). There were no significant interactions between experiments (1 and 2) and the exact concentrations, therefore, the results will be discussed by plant species averaged across experiments (Table 1).

Table 1. Analysis of variance (ANOVA) for percentage germination of red morningglory, redroot pigweed, and spiny pigweed for source factors experiments, treatments, and experiment x treatment

Source	Red Morningglory	Redroot Pigweed	Spiny Amaranth
	Pr > F	Pr > F	Pr > F
Experiment	0.0203	0.8474^{Z}	0.4462^{Z}
Extract Concentration	0.0011	0.0018	<.0001
Experiment x Concentration	0.0568^{Z}	0.3687^{Z}	0.0584^{Z}

Note. ^{Z}Not Significantly Different at $P \leq 0.05$, ANOVA.

3.2 Red Morningglory

The sugarcane field residue only inhibited red morningglory germination at the 100 g/L concentration, 29% germination reduction, while the sugarcane root extracts inhibited morningglory germination at the 25 g/L and 100 g/L concentration, resulting in a 15.5% and 19.5% decrease in germination, respectively (Table 2). The 100 g/L field residue concentration was 9.5% more effective at reducing red morning glory germination than the 100 g/L root concentration, and 13.5% more effective than the 25 g/L root concentration. The sugarcane field residue extracts results are consistent with earlier research by Viator et al. (2006), which showed that increasing field residue concentration decreased morningglory germination. The sugarcane root extract impact is the first documented account of sugarcane roots being allelopathic to any plant species.

Table 2. Impact of sugarcane field residue and root extract concentrations on red morning glory, redroot pigweed, and spiny pigweed germination percentage

Extract Source & Concentration	Red Morningglory Germination Averaged Across Experiments		Redroot Pigweed Germination Averaged Across Experiments		Spiny Amaranth Germination Averaged Across Experiments	
	%		%		%	
Field Residue						
0 g/L	47.5	a[Z]	58.5	a	88.5	ab
12.5 g/L	44.5	ab	42.0	d	85.5	ab
25 g/L	39.5	abc	52.5	abc	82.5	b
50 g/L	38.0	abc	43.0	cd	59.5	c
100 g/L	18.5	d	41.0	d	8.0	d
Roots						
0 g/L	47.5	a	58.5	a	88.5	ab
12.5 g/L	36.5	abc	53.5	ab	89.0	ab
25 g/L	32.0	bc	46.0	bcd	91.5	a
50 g/L	44.5	ab	45.5	bcd	86.5	ab
100 g/L	28.0	cd	40.0	d	84.5	ab

Note. [Z]Means in a column followed by the same lower case letter are not significantly different at $P \leq 0.05$, ANOVA.

3.3 Redroot Pigweed

Sugarcane field residue and extracts also inhibited redroot pigweed germination across both experiments (Table 2). Although the redroot pigweed germination percentage decrease was not as great as red morningglory, the data indicated a greater significant difference compared to the control (0 g/L). The sugarcane field residue decreased redroot pigweed germination at the 12.5, 50, and 100 g/L concentrations by 16.5%, 15.5%, and 17.5%, respectively. The sugarcane field residue results are consistent with Webber et al. (2015a) who reported a corresponding decrease in redroot pigweed germination as kenaf leaf extracts increased from 0 g/L to 66.7 g/L. Sugarcane root extracts performed in a similar manner as the residue extracts, decreasing redroot pigweed germination at the 25, 50, and 100 g/L extract concentrations by 12.5%, 13%, and 18.5%, respectively. As with the red morningglory germination, this is the first known documentation that sugarcane roots have allelopathic activity. The 100 g/L residue and root extract impacted germination rates in a similar manner, both decreasing germination compared to the control (0 g/L). The allelopathic impact of the sugarcane residue and roots on redroot pigweed are consistent with research with sorghum residue and root extracts on redroot pigweed (Panasiuk et al., 1986; Yarnia et al., 2009).

3.4 Spiny Amaranth

Spiny amaranth responded to sugarcane field residue and root extracts differently than red morningglory and redroot pigweed (Table 2). Averaged across experiments, spiny amaranth germination was significantly less with the 50 and 100 g/L sugarcane field residue extracts by 29%, and 80.5%, respectively. The 100 g/L field residue concentration reduced spiny amaranth germination the most among the 3 weed species tested across all experiments and extract concentrations. In contrast to the redroot pigweed, the root extracts did not significantly affect spiny amaranth germination at any concentration, while the redroot pigweed germination decreased at the 25, 50, and 100 g/L concentrations of root extracts.

4. Conclusions

Seed germination generally decreased with increasing sugarcane field residue extract concentrations in the 3 weed species tested. At the highest residue concentration (100 g/L), red morning glory, redroot pigweed, and spiny amaranth germination decreased by 29%, 17.5% and 80.5%, respectively. Germination generally decreased with increasing sugarcane root extract concentrations in red morningglory and redroot pigweed, but not with spiny amaranth. The highest root extract concentration (100 g/L) decreased red morningglory and redroot pigweed germination by 19.5% and 18.5%, respectively. This research provides the first bioassay demonstrating that sugarcane root extracts have allelopathic activity, and specifically on red morningglory and redroot pigweed germination. Future research should investigate the allelopathic compounds present in the sugarcane field

residue and roots, determine if the same allelopathic compounds are present and in similar concentrations among other sugarcane varieties, and further examine which weed species may be vulnerable to the allelopathic compounds present in sugarcane roots.

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