Journal of Agricultural Science; Vol. 7, No. 12; 2015
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Kenaf (*Hibiscus cannabinus* L.) Impact on Post-Germination Seedling Growth

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Received: September 14, 2014 Accepted: October 26, 2015 Online Published: November 15, 2015

doi:10.5539/jas.v7n12p91 URL: http://dx.doi.org/10.5539/jas.v7n12p91

Abstract

The chemical interaction between plants, which is referred to as allelopathy, may result in the inhibition of plant growth and development. The objective of this research was to determine the impact of kenaf (*Hibiscus cannabinus* L.) plant extracts on the post-germination growth of five plant species. Four concentrations (0, 16.7, 33.3 and 66.7 g/L) of kenaf bark, core, and leaf extracts were applied to the germinated seeds of redroot pigweed (*Amaranthus retroflexus* L.), green bean (*Phaseolus vulgaris* L.), tomato (*Solanum lycopersicum* Mill.), cucumber (*Cucumis sativus* L.), and Italian ryegrass (*Lolium multiflorum* Lam.). After 7 days, the developing seedlings were measured to determine the length of their hypocotyls (mm) and radicles (mm), and the number of hair roots. Tomato, Italian ryegrass, and redroot pigweed followed similar negative trends in their responses to the extract source (kenaf bark, core, and leaves) and the impact of extract concentration, whereas, cucumber had a mixed response and green bean reacted positively to the kenaf extracts. Tomato was the most sensitive species tested across all kenaf extracts and concentrations, resulting in decreased hypocotyl, radicle, and root growth. Green bean exhibited no negative effects due to the kenaf extracts, but actually produced increased hypocotyl growth as a result of the kenaf bark, core, and leaf extracts. The kenaf extracts resulted in a mixed response for cucumber. The kenaf leaf and bark extract decreased cucumber radicle growth, whereas, the bark and core extracts increased hypocotyl growth. Italian ryegrass hypocotyl growth decreased across all extract sources (bark, core, and leaf), while the leaf extract also reduced root growth. All kenaf extracts reduced redroot pigweed radicle growth, while the core and leaf extracts reduced hypocotyl growth. The research demonstrated that kenaf leaf extracts were the most allelopathic and the hypocotyls were the most sensitive. Future research should isolate the chemicals responsible for both the negative and positive allelopathic impact on the various plant species, determine if the extracts will influence more mature plants, and pursue cultural practices to utilize these natural allelopathic materials to benefit crop production and limit weed competition.

Keywords: allelopathy, cucumber, green bean, hypocotyl, Italian ryegrass, kenaf, pestiphytology, radicle, redroot pigweed, seed germination, tomato, weed control

1. Introduction

1.1 Allelopathy

"Allelopathy" as coined and defined by Molisch (1937) is the biochemical interaction between plants, whether inhibiting or stimulating plant growth and development. Many plant species are now known to produce chemicals, which when released into the environment can impact the growth and development of other plants (Rice, 1984). The demand by the general public for 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.

1.2 Kenaf

Kenaf is a warm season annual fiber crop in the same family as cotton (*Gossypium hirsutum* L., Malvaceae) and okra (*Abelmoschus esculentus* L., Malvaceae) that can be successfully produced in various areas of the United States, particularly in the southern states (Webber & Bledsoe, 1993). The commercial use of kenaf continues to diversify from its historical role as a cordage crop (rope, twine, and sackcloth) to its various new applications including paper products, building materials, absorbents, and livestock feed (Webber & Bledsoe, 1993).

Historically, kenaf has been used as a cordage crop to produce twine, rope, and sackcloth for over six millennia (Dempsey, 1975). Kenaf was first domesticated and used in northern Africa. India has produced and used kenaf for the last 200 years, while Russia started producing kenaf in 1902 and introduced the crop to China in 1935 (Dempsey, 1975). In the United States, kenaf research and production began during World War II to supply cordage material for the war effort (Wilson et al., 1965). The war not only interrupted the foreign fiber supplies from countries such as the Philippines, but the US involvement in the war also increased the use of these fibers by the US.

Once it was determined that kenaf was suited for production in the US, research was initiated to maximize US kenaf yields. As a result, scientists successfully developed high-yielding anthracnose-resistant cultivars, cultural practices, and harvesting machinery that increased fiber yields (Nieschlag et al., 1960; White et al., 1970; Wilson et al., 1965). Then in the 1950s and early 1960s, as USDA researchers were evaluating various plant species to fulfill future fiber demands in the US, it was determined that kenaf was an excellent cellulose fiber source for a large range of paper products (newsprint, bond paper, and corrugated liner board). It was also determined that pulping kenaf required less energy and chemical inputs for processing than standard wood sources (Nelson et al., 1962). More recent research and development work in the 1990s demonstrated the plant's suitability for use in building materials (particle boards of various densities, thicknesses, with fire and insect resistance), adsorbents, textiles, livestock feed, and fibers in new and recycled plastics (injected molded and extruded) (Webber & Bledsoe, 1993).

1.3 Kenaf and Allelopathy

Research by Russo et al. (1997a) comparing the impact of plastic and kenaf mulches on soil erosion and production of vegetable crops indicated that the kenaf mulch may have had an allelopathic influence on the growth of some vegetables. A kenaf mulching study further indicated that extracts from non-weathered kenaf plant material decreased germination of redroot pigweed, annual ryegrass, tomato, and cucumber, while having no impact on green bean germination (Russo et al., 1997b). In addition, whereas redroot pigweed germination continued to be detrimentally impacted across all mulching treatments (non-weather, 2 month weathered, and 4 month weathered kenaf) as the extract concentration increased, there appeared to be no ill effects on the other seedlings due to exposure to the weathered kenaf (Russo et al., 1997b). These research studies provided a clear indication that kenaf plant material had allelopathic characteristics, but the research did not isolate which portion of the kenaf plant, leaves or stems, were allelopathic. In addition, related species in the Malvaceae family have exhibited allelopathic activity. Chuah et al. (2011) reported that the aqueous extracts of pods of a related plant species, okra (*Abelmoschus esculentus* L.), inhibited goosegrass (*Eleusine indica* L. Gaertn) germination and seedling growth. Jalali et al. (2013) determined that aqueous leaf extracts of the common mallow (*Malva sylvestris*) also exhibited allelopathic activity decreasing the germination and seedling growth of blanket flower (*Gaillardia pulchella*), plumed cockscomb (*Celosia argentea*), and sweet William (*Dianthus barbatus*). Webber et al. (2015) when examining the impact of different concentrations of kenaf bark, core, and leaf extracts, determined that the kenaf leaf extracts were allelopathic, reducing seed germination of tomato, cucumber, Italian ryegrass and redroot pigweed.

To maximize the use of allelopathic activity of kenaf as a positive influence in agriculture, it is important to isolate the portion of the kenaf plant that is most allelopathically active and determine the impact across numerous plant species. It is also important to determine if the previous noted allelopathic activity of kenaf extracts would also effect post-germination growth. The purpose of this research was to determine whether any portion of the kenaf plant exhibited allelopathic activity on the post-germinated growth across different species.

2. Material and Methods

2.1 Kenaf Plant Material Preparations

Mature, 186 day-old, kenaf plants, were harvested at ground level in October prior to a killing frost. The plants were immediately separated into three major plant components, leaves, bark (stem bark), and core (stem core). The few flower and seed pods present were discarded and not included in the experiment. The separate plant portions

(leaves, bark, and core) were then dried in a forced air oven for 48 h or until constant weight at 66 °C. The samples were then ground using a Thomas-Wiley Laboratory Mill with a 1 mm sieve.

2.2 Kenaf Extract Preparations

The plant materials and distilled water were added to 3000 ml flasks and placed on a Lab-Line Orbit Shaker at 100 rpm for 12 h at room temperature (22 °C). The samples were vacuum filtered through Whatman # 42 filter paper twice. The samples were then diluted as needed with distilled water to produce concentrations of 66.7 g/L (full strength), 33.3 g/L (half strength), and 16.7 g/L (quarter strength) solutions of kenaf leaf, bark, and core extracts. The pH for all dilutions was adjusted to 7.0 using 1M KOH and 1M HCl.

2.3 Post-Germination Treatment

Seeds of green bean (*Phaseolus vulgaris* L.) var. 10 Hystyle, tomato (*Solanum lycopersicum* Mill.), cucumber (*Cucumis sativus* L.) var. 403 Royal, annual Italian ryegrass (*Lolium multiflorus* Lam.), and redroot pigweed (*Amaranthus retroflexus* L.) were surface sterilized for 1 min using a 50% sodium hypochlorite solution. The seeds were then rinsed with water and allowed to air dry for 10 min. Forty seeds of each plant species were placed in separate Petri plates which contained 2.9 cm Whatman No. 2 filter papers. To each Petri plate was added 10 ml of distilled water. The Petri plates were covered and placed in a non-illuminated incubator at 27 °C to promote germination. After 7 days, 25 uniformly germinated seeds were selected; surface sterilized for 1 min using a 50% sodium hypochlorite solution, and placed in new Petri plates which contained 2.9 cm Whatman No. 2 filter papers. Seeds were considered germinated when the seed radicle was at least the length of the width of seed of the specific plant species being measured. To each Petri plate containing the 25 germinated seeds was added 10 ml of either kenaf plant extract (leaf, bark, or core) at each of the concentrations [66.7 g/L, 33.3 g/L, 16.7 g/L, and 0 g/L (distilled water)]. After 7 days, the developing seedlings were measured to determine the length of their hypocotyls (mm) and radicles (mm), and the number of root hairs.

This post-germination experiment was conducted twice. Each experiment included 3 kenaf plant extracts (bark, core, and leaf), 4 concentrations [0 (control), 16.7, 33.3 and 66.7 g/L], five plant species (green bean, tomato, cucumber, annual Italian ryegrass, and redroot pigweed), and 5 replications. All data were subjected to ANOVA and mean separation using LSD with P = 0.05 (SAS Inc., SAS, Ver. 9.0, Cary, NC).

3. Results and Discussion

3.1 Statistical Analysis

Statistical analysis determined that there were significant interactions among plant species (green bean, tomato, cucumber, Italian ryegrass, and redroot pigweed), among sources of kenaf extracts (bark, core, and leaf), and among extract concentrations (0, 16.7, 33.3 and 66.7 g/L). Therefore, the results will be discussed by plant species with each interaction addressed separately.

3.2 Green Bean

3.2.1 Green Bean Hypocotyl Growth

Significant interactions were detected between the extract concentrations and experiments; therefore, the hypocotyl data will be discussed by each of the three plant part extract sources and by experiments (Table 1). The extract concentration did result in a significant difference in hypocotyl growth for each of the sources of extract (Table 1). The presence of any level of kenaf extract above the control (0 g/L) increased the hypocotyl length compared to the control. Although there is not a clear trend between experiments, all experiments for each of the extract sources produced accelerated hypocotyl growth for green bean plants. These results are consistent with earlier research by Russo et al. (1997b) and Webber et al. (2015) who observed little or no detrimental impact of kenaf extract concentrations on green bean germination. Also, as reported by Webber et al. (2015), there was a slight beneficial impact of the kenaf bark and leaf extracts on seed germination, which is consistent with a potential benefit to post-germination growth of the green bean hypocotyl.

Table 1. Impact of the kenaf extract source (core, bark, and leaf) and extract concentration on green bean hypocotyl lengths

Concentration[Z]	Bark		Core		Leaves	
	Experiment 1 (mm)	Experiment 2 (mm)	Experiment 1 (mm)	Experiment 2 (mm)	Experiment 1 (mm)	Experiment 2 (mm)
0 g/L	69.2 d[z]	49.1 c	69.2 c	49.1 d	69.2 d	49.1 c
16.7 g/L	79.2 c	84.1 a	90.6 a	61.5 c	93.6 a	82.3 b
33.3 g/L	96.5 a	74.9 b	81.1 b	77.5 b	88.1 b	89.6 a
66.7 g/L	86.8 b	80.0 a	81.1 b	90.4 a	75.2 c	86.5 ab

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

3.2.2 Green Bean Radicle Growth

No significant interactions were detected between the experimental factors of plant part and either extract concentration or experiment for radicle growth. As a result, green bean radicle growth data will be discussed averaged across plant parts, extract concentrations, and experiments (Table 2). Unlike hypocotyl length, green bean radicle lengths were not significantly affected by either source of the kenaf extract or by extract concentration (Tables 2). These results are consistent with Russo et al. (1997b) and Webber et al. (2015) who determined that of the five seed types evaluated, green bean was the least detrimentally impacted by kenaf extracts.

Table 2. Influence of kenaf plant extracts (bark, core, and leaves) and extract concentrations (0, 16.7, 33.3, and 66.7 g/L) on green bean post-germination radicle growth (mm)

	Radicle Length (mm)
Kenaf Plant Part[Z]	
Bark	67.1 a[X]
Core	62.3 a
Leaves	65.2 a
Extract Concentration[Y]	
0 g/L	65.6 a
16.7 g/L	60.5 a
33.3 g/L	71.7 a
66.7 g/L	61.8 a

Note. [Z]Kenaf plant part means averaged across the four extract concentrations and two experiments.

[Y]Extract concentration means averaged across kenaf plant parts and two experiments.

[X]Means in a column within a main effect (kenaf plant part, extract concentration, and experiment) followed by the same lower case letter are not significantly different at $P \leq 0.05$, ANOVA.

3.2.3 Green Bean Roots

There was a significant extract concentration by experiment interaction for root hair number, therefore the impact of the plant extract source will be discussed separately (Table 3) from the impact for extract concentration by experiment (Table 4). Although the green bean root hair numbers did not exhibit differences when comparing the kenaf extracts source averaged across extract concentrations and experiments (Table 3), there was a decrease in root numbers when the data was separated by extract source (bark, core, and leaf) and experiments (Table 4). The interaction between experiments and extract concentration and the adverse impact of the extract on root hair numbers (Table 4) is an indication that there is an allelopathic impact on green bean root hairs, but the trend is not consistent.

Table 3. Influence of kenaf plant extracts (bark, core, and leaves) averaged across extract concentrations (0, 16.7, 33.3, and 66.7 g/L) and experiments on green bean post-germination root hair number

Kenaf Plant Part[Z]	Root Hair Number (#)
Bark	21.5 a[Y]
Core	22.7 a
Leaves	20.1 a

Note. [Z]Kenaf plant part means averaged across the four extract concentrations and the two experiments.

[Y]Means in a column within a main effect (kenaf plant part, extract concentration, and experiment) followed by the same lower case letter are not significantly different at $P \leq 0.05$, ANOVA.

Table 4. The impact of kenaf extract concentrations (0, 16.7, 33.3, and 66.7 g/L) for each kenaf plant extract source (core, bark, and leaves) on root hair numbers 7 days post-germination

Concentration[Z]	Bark		Core		Leaves	
	Exp 1 (#)	Exp 2 (#)	Exp 1 (#)	Exp 2 (#)	Exp 1 (#)	Exp 2 (#)
0 g/L	23.6 a[Y]	24.2 b	23.6 a	24.2 a	23.6 a	24.2 a
16.7 g/L	23.4 a	18.3 c	25.5 a	19.8 b	22.8 a	17.0 b
33.3 g/L	13.0 b	22.0 bc	23.2 a	24.7 a	20.9 a	16.8 b
66.7 g/L	17.4 b	30.2 a	14.6 b	26.0 a	13.6 b	22.0 a

Note. [Z]Extract concentration means averaged across the kenaf core, bark, or leaf extracts and across 2 experiments.

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

3.2.4 Green Bean Summary

It was determined that the application of kenaf leaf abstracts on germinated green beans increased hypocotyl growth, did not impact radicle growth, and produced a trend of reducing root hair numbers but without a clear response to concentration. These results are consistent with earlier research by Russo et al. (1997b) who reported that green bean germination was the least detrimentally impacted when exposed to whole plant kenaf extracts compared to the same plant species. Webber et al. (2015) also reported mixed results concerning the impact of different kenaf plant extracts on green bean germination, indicating that the core extracts actually increased germination and the extract concentration did not produce a clear trend. Perhaps a higher concentration of the kenaf extracts might produce a clearer trend to determine if the material is consistently beneficial or detrimental.

3.3 Tomato

Due to the absence of a plant part by extract concentration by experiment interaction, the tomato post-germination data will be reported averaged across experiments (Table 5).

3.3.1 Tomato Hypocotyl Growth

Hypocotyl growth was adversely affected by the highest extract concentration (66.7 g/L), independently of the source of the extract (Table 5). In addition, the severity of the damage to hypocotyl growth was different depending of the plant source. The increasingly adverse impact was the least for the core, then the bark, and finally the leaf extract, which produced the most severe impact on hypocotyl growth (Table 5).

3.3.2 Tomato Radicle Growth

Radicle growth was affected by both the extract concentration and extract source (Table 5). The radicle growth was very sensitive to any level of extract, showing, at least, a 65% decrease in radicle growth when comparing the extract control (0 g/L) to any of the extract concentrations (Table 5). As with the hypocotyl lengths, the leaf extracts had the greatest detrimental impact of the radicle growth (Table 5).

3.3.3 Tomato Root Hairs

The number of tomato root hairs decreased as extract concentrations increased, while kenaf bark and leaf extracts decreased hair roots more than the core extracts.

3.3.4 Tomato Summary

Increasing the extract concentration decreased tomato hypocotyl and radicle growth, and root numbers (Table 5). These results are consistent with Webber et al. (2015), who reported that tomato seed germination decreased as extract concentration increased for different sources of kenaf plant extracts. The core extracts was the least impactful on post-germination growth, while leaf extracts were the most detrimental on hypocotyl and radicle growth, and root numbers (Table 5). These results on post-germination development are consistent with earlier research by Russo et al. (1997b) who reported sensitity of tomato seeds to whole plant kenaf extracts and Webber et al. (2015) who reported that tomato seed germination was most sensitive to kenaf leaf extracts.

Table 5. Influence of kenaf plant extracts (bark, core, and leaves) and extract concentrations (0, 16.7, 33.3, and 66.7 g/L) on tomato post-germination growth (hypocotyl length, radicle length, and root number)

	Hypocotyl Length (mm)	Radicle Length (mm)	Root Hair Number (#)
Kenaf Plant Part[Z]			
Bark	65.4 b[X]	11.3 ab	2.0 b
Core	73.0 a	12.4 a	2.3 a
Leaves	51.0 c	9.5 b	1.9 b
Extract Concentration[Y]			
0 g/L	64.4 b	22.1 a	2.6 a
16.7 g/L	71.1 a	7.8 b	2.4 a
33.3 g/L	65.2 b	7.1 b	2.1 b
66.7 g/L	51.8 c	7.3 b	1.2 c

Note. [Z]Kenaf plant part means averaged across the four extract concentrations and the two experiments.

[Y]Extract concentration means averaged across kenaf plant parts and two experiments.

[X]Means in a column within a main effect (kenaf plant part, extract concentration, and experiment) followed by the same lower case letter are not significantly different at $P \leq 0.05$, ANOVA.

3.4 Cucumber

Due to the various interactions, the cucumber data will be separated and discussed by extract concentration, kenaf plant extract source, and experiment (Table 6).

3.4.1 Cucumber Growth

The kenaf leaf and bark extract consistently decreased cucumber radicle growth across both experiments, whereas the bark and core extracts consistently increased hypocotyl growth (Table 6). The beneficial impact of the kenaf bark and core extracts on hypocotyl growth is consistent with the Webber et al. (2015) who reported elevated cucumber germination from the kenaf bark and core extracts. These results further explain the beneficial impact of whole plant kenaf extracts reported by Russo et al. (1997b) on cucumber germination due to the greater proportion of bark and core plant material in their mulching experiments.

Table 6. Impact of the kenaf extract source (core, bark, and leaf) and extract concentration on cucumber hypocotyl and radicle lengths, and root hair number by experiments

Kenaf Extract	Concentration	Hypocotyl		Radicle		Root Hair Number	
		Exp 1 (mm)	Exp 2 (mm)	Exp 1 (mm)	Exp 2 (mm)	Exp 1 (#)	Exp 2 (#)
Bark	0 g/L	106.6 d[z]	120.5 c	93.9 a	98.0 a	12.8 c	24.3 a
	16.7 g/L	132.2 c	150.1 b	91.5 a	79.7 b	21.2 a	17.8 b
	33.3 g/L	140.9 b	158.4 a	81.1 b	69.4 c	16.9 b	18.5 b
	66.7 g/L	147.0 a	158.5 a	73.1 c	64.6 d	13.2 c	11.9 c
Core	0 g/L	106.6 d	120.5 d	93.9 a	98.0 a	12.8 c	24.3 a
	16.7 g/L	126.3 c	138.4 c	94.1 a	89.6 b	20.7 a	21.7 a
	33.3 g/L	138.2 b	153.8 b	94.2 a	84.7 c	16.7 b	22.0 a
	66.7 g/L	152.1 a	165.5 a	92.0 a	81.3 c	16.3 b	21.9 a
Leaves	0 g/L	106.6 b	120.5 d	93.9 a	98.0 a	12.8 b	24.3 a
	16.7 g/L	129.8 a	155.1 b	81.8 b	61.7 b	18.3 a	14.9 bc
	33.3 g/L	139.8 a	161.6 a	56.4 c	64.9 b	10.8 c	17.9 b
	66.7 g/L	86.9 c	149.1 c	38.4 d	55.5 c	7.7 d	12.9 c

Note. [z]Means in a column within the kenaf extract main effect (bark, core, and leaves) followed by the same lower case letter are not significantly different at $P \leq 0.05$, ANOVA.

3.4.2 Italian Ryegrass

Italian ryegrass hypocotyl growth decreased across both experiments for all extract sources (bark, core, and leaf) when comparing the control (0 g/L) to the highest extract concentration (66.7 g/L) (Table 7). Averaged across experiments, Italian ryegrass hypocotyl growth decreased by 6.4%, 5.2%, and 22.2% from the 0 g/L concentration (control) to the 66.7 g/L concentration for the bark, core, and leaf extracts, respectively. These results are consistent with Webber et al. (2015) where the kenaf leaf extracts resulted in the greatest decrease in Italian ryegrass germination. The impact of extract concentration and source of extract was inconsistent for Italian ryegrass radicle growth and root hair number (Table 7).

Table 7. Impact of the kenaf extract source (core, bark, and leaf) and extract concentration on Italian ryegrass hypocotyl and radicle lengths, and root hair number by experiments

Kenaf Extract	Concentration	Hypocotyl		Radicle		Root Hair Number	
		Exp 1 (mm)	Exp 2 (mm)	Exp 1 (mm)	Exp 2 (mm)	Exp 1 (#)	Exp 2 (#)
Bark	0 g/L	100.7 a[z]	121.1 a	26.7 a	44.4 a	2.9 a	0.5 a
	16.7 g/L	100.0 a	112.4 c	26.2 a	46.1 a	1.8 b	0.7 a
	33.3 g/L	95.8 b	116.9 b	30.9 a	42.5 a	2.1 b	0.9 a
	66.7 g/L	90.6 c	117.0 b	19.1 b	44.8 a	2.5 ab	0.7 a
Core	0 g/L	100.7 a	121.1 a	26.7 b	44.4 b	2.9 a	0.5 a
	16.7 g/L	98.0 a	120.1 a	24.4 b	48.3 a	3.0 a	0.7 a
	33.3 g/L	101.3 a	118.2 ab	32.7 a	48.9 a	2.3 a	0.7 a
	66.7 g/L	93.5 b	116.6 b	20.8 c	46.0 ab	2.8 a	0.8 a
Leaves	0 g/L	100.7 a	121.1 a	26.7 a	44.4 a	2.9 a	0.5 a
	16.7 g/L	96.7 b	116.8 b	18.9 b	44.2 a	2.8 a	0.5 a
	33.3 g/L	89.3 c	101.2 c	23.7 a	41.3 a	2.2 b	0.4 a
	66.7 g/L	79.9 d	92.4 d	17.8 b	43.0 a	2.2 b	0.1 b

Note. [z]Means in a column within the kenaf extract main effect (bark, core, and leaves) followed by the same lower case letter are not significantly different at $P \leq 0.05$, ANOVA.

3.4.3 Redroot Pigweed

The kenaf leaf extracts exhibited the greatest and most consistent detrimental impact on redroot pigweed hypocotyl and radicle growth for both experiments (Table 8). As with Italian ryegrass, these results are consistent with Webber et al. (2015) where the kenaf leaf extracts resulted in the greatest decrease in germination. The bark extracts did decrease redroot pigweed radicle growth, although the impact was not as great as with the leaf extracts (Table 8). These results along with the earlier research by Russo et al. (1997b) and Webber et al. (2015) strongly suggest there is a potential of using kenaf leaf extracts as a natural herbicide to reduce redroot pigweed germination and initial seedling growth.

Table 8. Impact of the kenaf extract source (core, bark, and leaf) and extract concentration on redroot pigweed hypocotyl and radicle lengths, and root number by experiments

Kenaf Extract	Concentration	Hypocotyl		Radicle		Root Hair Number	
		Exp 1 (mm)	Exp 2 (mm)	Exp 1 (mm)	Exp 2 (mm)	Exp 1 (#)	Exp 2 (#)
Bark	0 g/L	37.4 ab[z]	38.4 b	19.1 a	16.3 a	0.1 a	0.5 a
	16.7 g/L	40.6 a	45.8 a	8.2 b	16.7 a	0.2 a	0.0 a
	33.3 g/L	35.2 b	38.2 b	9.1 b	12.1 b	0.1 a	0.1 a
	66.7 g/L	39.2 a	36.4 b	7.9 b	9.8 c	0.1 a	0.0 a
Core	0 g/L	37.4 a	38.4 c	19.1 a	16.3 a	0.1 a	0.5 a
	16.7 g/L	34.1 a	57.1 a	8.6 b	14.4 ab	0.5 a	0.2 a
	33.3 g/L	20.2 b	46.1 b	4.8 c	13.5 b	0.5 a	0.0 a
	66.7 g/L	23.7 b	39.3 c	4.3 c	12.4 b	0.2 a	0.4 a
Leaves	0 g/L	37.4 a	38.4 a	19.1 a	16.3 a	0.1 a	0.5 a
	16.7 g/L	27.7 b	42.7 a	5.0 b	11.4 b	0.3 a	0.0 b
	33.3 g/L	23.0 c	26.5 b	2.5 c	8.5 b	0.0 a	0.0 b
	66.7 g/L	6.8 d	18.9 c	0.4 d	10.0 b	0.0 a	0.0 b

Note. [z]Means in a column within the kenaf extract main effect (bark, core, and leaves) followed by the same lower case letter are not significantly different at $P \leq 0.05$, ANOVA.

4. Conclusions

Tomato was the most sensitive species tested across all kenaf extracts and concentrations, resulting in decreased tomato hypocotyl, radicle, and root growth. Green bean exhibited no negative effects due to the kenaf extracts, but actually produced increased hypocotyl growth as a result of the kenaf bark, core, and leaf extracts. The kenaf extracts resulted in a mixed response for cucumber in that the kenaf leaf and bark extract decreased radicle growth, whereas, the bark and core extracts increased hypocotyl growth. Italian ryegrass hypocotyl growth decreased across all extract sources (bark, core, and leaf), while the leaf extract also reduced root growth. All kenaf extracts reduced redroot pigweed radicle growth, while the core and leaf extracts reduced hypocotyl growth. Tomato, Italian ryegrass, and redroot pigweed followed similar negative trends in their responses to the extract source (kenaf bark, core, and leaves) and the impact of extract concentration, whereas, cucumber had a mixed response and green bean reacted positively to the kenaf extracts. The research demonstrated that kenaf leaf extracts were the most allelopathic and the hypocotyls were the most sensitive. Future research should isolate the chemicals responsible for both the negative and positive allelopathic impact on the various plant species, determine if the extracts will influence more mature plants, and pursue cultural practices to utilize these natural allelopathic materials to benefit crop production and limit weed competition.

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