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Allelopathic effects of Bermuda grass (*Cynodon dactylon* L.) root exudates on seed germination and seedling growth of Tall fescue (*Festuca arundinacea* Schreb)

Z.Y. Liang [†1,2], X.Y. Li [†1], H. Zhang[1], J. Li[1], X.J. Bian[2], J.C. Xu[1,*]
National Engineering Laboratory for Tree Breeding, College of Biological Sciences and Technology, Beijing Forestry University, Beijing 100083, China
E-mail: jcxu282@sina.com

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ABSTRACT

We studied the effects of Bermuda grass (*Cynodon dactylon* L.) 'Baoding' root exudates on seed germination, biomass and physiological elements of 6- Tall fescue (*Festuca arundinacea*) cultivars. GC-MS analysis detected 23 compounds in Bermuda grass 'Baoding' root exudates including esters (50.31%), alkanes (17.03%) etc. However of them, the compound 3-Phenylpropyl 4-methylbenzoate was in highest content (34.73%) followed by octadecanamide (13.81%). The root exudates of Bermuda grass 'Baoding' at 0.75 $mg \cdot ml^{-1}$ concentration stimulated the Tall fescue cultivars, but 1.50 $mg \cdot ml^{-1}$ concentration was inhibitory. Further, Bermuda grass 'Baoding' root exudates were cultivar and tissue specific to Tall fescue. The Tall fescue cultivar *Justice* displayed more sensitivity, while *Greenlabel* roots were more sensitive than shoots. Thus, mix-sowing of Bermuda grass with Tall fescue plants in proper proportion was suggested.

Key words: Allelopathy, Bermuda grass, compounds, *Cynodon dactylon*, *Festuca arundinacea*, GCMS, mix-sowing, root exudates, seed germination, seedling growth, Tall Fescue

INTRODUCTION

Mix-planting is common and widely used to avoid continuous cropping problem by single species monoculture (21,25). It also improves the plant resistance (3,22,27,36), diversity (5,26), yield (15) and landscape (35). The allelopathic effects are important factors for successful mix-sowing, but it has received little attention (8,29).

Plants release allelochemicals [phenols, terpenes, sugars and glycosides (1,4,19)] which affects other plant species through their release as root exudates, volatilization, leaching and biomass decomposition (18). Zuo (39) studied 5-types of allelochemicals inhibitory to *Chlorella* and found that the allelochemicals had the synergistic and antagonistic role. Rehman (30) reported that combined application of mixture of allelopathic water extracts of sorghum, sunflower and rice with 1/2 recommended dose of pre-emergence herbicides significantly reduced the barnyard grass, flat sedge and crowfoot grass density. Mixed-planting has great potential in turf grass management (13). Thus, allelopathy could be applied to agricultural production (33) and urban landscaping (32).

Bermuda grass (*Cynodon dactylon*) is most common perennial warm-season turf grass and widely used in the courtyard lawn, urban landscapes etc. It establishes quickly and has fast growth but poor resistance to cold (10). Tall fescue (*Festuca arundinace*) is perennial cool-season grass and important in grasslands and natural grassland reseeding in temperate zones of the world (17). Its plants have rapid growth, strong regeneration but

*Correspondence author, [1]College of Animal Science and Technology, Hebei Agricultural University, Baoding, Hebei 071001, China, † Liang Zhongyin and Li Xiaoyu contributed equally to this work.

poor heat resistance. Mixed-sowing of both these species may complement each other and maintain the grasslands. This study aimed to determine the effects of root exudates of Bermuda grass on seed germination and seedling growth of *F. arundinacea* cultivars to provide us in sight in the grass mixtures.

MATERIALS AND METHODS

Germplasm of Bermuda grass was obtained from Hebei Agricultural University, China. The *F. arundinacea* 6-cultivars: *Justice, Arid3, Commander, Greenlabel, Escalad* and *Ayres* were provided by Beijing Top Green Company Ltd. The 200 grass seeds of each cultivar were soaked in 1.00 ml deionized water for 24 h, then disinfected by 1% NaCIO for 5 min and washed thrice with distilled water. These seeds were sown on surface of pot (10×10×12 cm) in growth chamber at normal growth conditions (Temperature 25ºC, photoperiod 16h light / 8h dark). Plants were irrigated every other day and fertilized weekly with half-strength Hoagland's nutrients solution (14).

BIOASSAYS

1. Extraction of Bermuda grass 'Baoding' **root exudates**

Bermuda grass plants were carefully pulled out, washed with water and cultured in distilled water for 2 days. All roots were harvested, dried and weighted. The culture solution was collected and diluted to 100 mg dried roots·ml^{-1} concentration for the GC-MS analysis. It was further diluted to 0 mg dried roots·ml^{-1}, 0.75 mg·ml^{-1}, and 1.50 mg·ml^{-1} (control) concentration respectively and kept at 4^{o}C for the allelopathic assay.

2. Gas chromatography-mass spectrometry (GC-MS) analysis

The Bermuda grass 'Baoding' root exudates solution at concentration of 100 mg dried roots·ml^{-1} was purified with filter paper and millipore filter (0.45 μm). Five ml of filtrate was mixed with 2 ml of ethyl acetate. 1μl of the ethyl acetate extract was analyzed by GCMS-Qp2010 Ultra GC-MS (manufactured by Shimadzu Corporation). The GC was equipped with a quartz capillary column Rtx-5MS column（30m×0.25mm×0.25μm). The GC conditions were set as follows: inlet temperature 250 ^{0}C, helium（99.99%）carrier gas flow at constant 1ml·min^{-1}, injector split ratio 10:1. The temperature program for GC started at 50 ^{0}C and increased at the rate of 15 ^{0}C ·min^{-1} to 180 ℃ for 5min, and then at the rate of 10 ^{0}C ·min^{-1} until it reached 250 ^{0}C for 15min. MS analysis was conducted in positive electron ionization (EI) mode. The source temperature was held at 230 ^{0}C, with an electron ionization potential of 70 eV. , and ions were scanned over the molecular weight (m/z) range of 33~ 400 atomic mass units (AMU). Each metabolite was identified via the standard mass spectrum database of NIST 11.lib and NIST11s.lib, and the relative content of each component was counted by area normalization.

3. Biomass and physiological index of *F. arundinacea* plants

The experimental treatments consisted of two factors: A: Bermuda grass root exudates concentrations: 3 (0, 0.75, 1.50 mg dried roots·ml^{-1}) and B: *F. arundinacea* 6-cultivars (*Justice, Arid3, Commander, Greenlabel, Escalad, Ayres)*. The root exudates were applied at 20 ml per pot in 2-weeks-old *F. arundinacea* plants on alternate days. The seedlings were harvested 14 d after the treatment, weighed for physiological indices.

(i). **Relative electrolyte leakage (REL)**: 1g leaves of *F. arundinacea* were soaked in 30 ml deionized water, and shaken overnight. The electrical conductivity of the

solution was measured as R1. The solution containing the leaves were further boiled for 15 min and shaken overnight. The electrical conductivity was determined as R2. Relative electrolyte leakage (REL) was calculated using the following formula of REL=R1/R2.

(ii). **Malondialdehyde (MDA) content (23):** 1g fresh leaves of *F. arundinacea* was ground in 1.5 ml of trichloroacetic acid (TCA). After centrifugation, the supernatant was mixed with 0.6% thiobarbituric acid (TBA) in equal volume and kept in boiling water bath for 15 min. The supernatant was detected for the absorbance value at wavelengths of 450, 532, and 600 nm. The MDA content ($\mu mol \cdot g^{-1}$) was calculated as under:

MDA content = [6.459 X (OD_{532} - OD_{600}) - 0.56×OD_{450}] × V/W

Where, OD: Optical density; V: Extraction volume (ml); W: Fresh sample weight (g)

(iii). **Soluble sugar content**: 0.1 g leaves of *F. arundinacea* were boiled for 20 min in 1 ml deionized water. After centrifugation, 50 µl supernatant was mixed with 450 µl distilled water and 2.5 ml anthrone reagent, then boiled for 10 min again. The absorbance value of the solution was measured at wavelength of 620 nm. The soluble sugar content (SSC) (µg/g FW) was calculated formulas under:

Soluble sugar content = $W_1 \times V_1 \times$dilution factor/($V_2 \times W_2 \times 10^6$)

Where, W_1: Soluble sugar content from the standard curve (µg), V_1: Extraction volume (ml); V_2 : Test sample volume (ml); W_2 : Fresh sample weight (g).

(iv). **Root activity**: 0.1g clean roots were harvested and mixed with 2.5 ml 0.4% TTC (2,3,5-triphenyltetrazolium chloride) in dark for 24 h. The root samples were then washed with distilled water, dried and soaked in 5 ml 95% ethanol at 60° C water bath for 4 h. Absorbance of the soaked solution at 490 nm was measured. The tripheny formazan (TTF) content was inferred with the standard curve and computed for the root vitality ($mg \cdot g^{-1} \cdot h^{-1}$) by TTF content/root dry weight/time.

4. Seed germination

Fifty healthy seeds of *F. arundinacea* each cultivar (*Justice, Arid3, Commander, Greenlabel, Escalad, Ayres*) were soaked in 10 ml deionized water for 24 h, then disinfected by 1% NaCIO for 5 min and washed thrice with distilled water. All 6 *F. arundinacea* cultivar seeds were sown in Petri dishes lined with 3-filter papers. Each petri dish was irrigated with 10 ml Bermuda grass root exudates (0, 0.75, 1.50 mg dried roots·ml^{-1}, on first day and subsequently) as per treatment. The petri dish were kept in incubator for germination. The seed germination was calculated as under:

Seed germination (%): Number of seeds germinated / Number of seeds sown × 100%.

5. Response index (IR) calculation

Response index for each treatment was calculated according to the formula: IR = (T_1–T_0)/ T_0 [T_0, the data at 0mg·ml^{-1} Bermuda grass 'Baoding' root exudates; T1, the data at 0.75 (or 1.5) mg·ml^{-1} Bermuda grass 'Baoding' root exudates]. If IR > 0, the allelopathic effect was positive, while it was negative if IR <0.

6. Statistical Analysis

Statistical analysis of data was done using the least significance test (LSD) by SAS (version 9.0, Cary, NC).

RESULTS AND DISCUSSION

I. GC-MS : Root exudates compounds identification

Twenty-three compounds were identified by Bermuda grass root exudates by GC-MS (Table1). These include esters (50.31%), alkane (17.03%), amide (13.84%), aromatic alcohol (10.25%), aromatic hydrocarbon (6.32%), aldehyde (0.74%), phenol (0.74%) and alkene (0.74%). The ester compound of 3-phenylpropyl 4-methylbenzoat was in highest amount (34.73%, of the total) followed by octadecanamide (13.81%) and 2,5-dimethylphenyl methanol (8.10%).

Table 1. The allellopathic compounds in Bermuda grass 'Baoding' root exudates by GC-MS analysis

Retention Time(min)	Molecular Weight	Chemical compound	Similarity Index	Area%
4.39	156	undecane	86	3.41
5.45	142	nonanal	91	0.74
6.36	254	3-Phenylpropyl 4-methylbenzoate	84	34.73
6.41	170	dodecane	94	2.67
6.61	150	2-methoxy-1,3,4-trimethylbenzene	84	6.32
6.85	136	2,5-dimethylphenyl methanol	92	8.10
7.04	136	3,5-dimethylphenyl methanol	89	2.15
7.30	254	3-Phenylpropyl 3-methylbenzoate	84	4.54
7.37	212	pentadecane	94	3.19
7.58	212	2,6,11-trimethyldodecane	81	0.64
7.86	268	3-Phenylpropyl 3-phenylpropionate	83	2.03
7.94	268	2,5-dimethylphenyl methyl ester	82	5.00
8.29	198	tetradecane	96	3.34
9.18	184	3-methyl-5-propylnonane	82	0.64
9.26	206	2,4-di-tert-butylphenol	89	0.74
9.53	352	1-Iodohexadecane	88	0.74
10.17	238	1-heptadecene	93	0.74
10.26	296	henicosane	96	2.33
11.68	240	heptadecane	88	0.80
13.65	296	2,6,10,15-tetramethylheptadecane	93	1.60
17.28	282	icosane	93	0.89
19.50	283	octadecanamide	93	13.81
19.80	478	N-trtra triacontane	89	0.77

II. *F. arundinacea* seed germination

The Bermuda grass root exudates at 0.75 mg·ml^{-1} concentration stimulated the seed germination of *F. arundinacea* cv's (Fig.1). The RI value for each cultivar ranged between 0.30-0.40 in 72 h treatment (Table 2). While the 1.50 mg·ml^{-1} Bermuda grass root exudates concentration inhibited the seed germination in all the *F. arundinacea* cultivars. The *Ayres* RI value 2 folds more than *Greenlabel* (Table 2).

III. *F. arundinacea* biomass

The Bermuda grass root exudates significantly affected the biomass of *F. arundinacea* than control (Table 3). The allelopathic effects were concentration dependent e.g. the root mass of *Justice* variety decreased by 14% and 44% at 0.75 and 1.50 mg·ml^{-1}

concentration of Bermuda grass root exudates, respectively. The Bermuda grass root exudates at 0.75 mg·ml^{-1} concentration increased the seedling biomass but decreased at 1.50 mg·ml^{-1} (Table 4). Thus lower concentration of root exudates was stimulatory to plant growth but higher concentration was inhibitory.

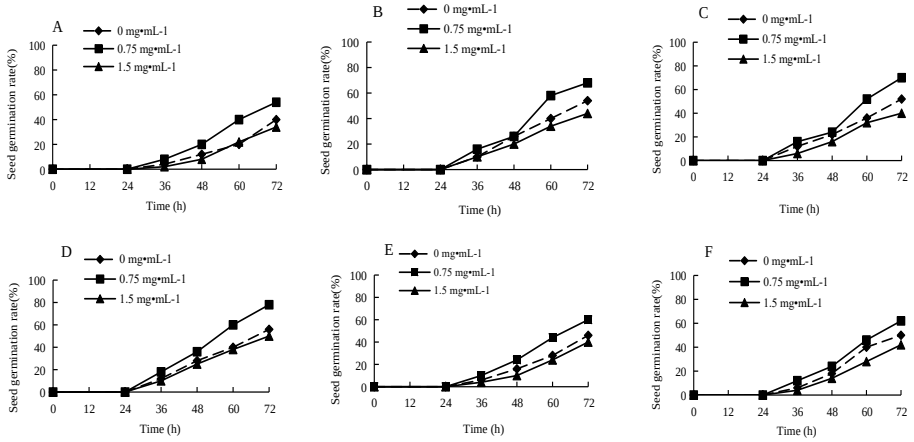

Fig. 1. Effects of Bermuda grass 'Baoding' root exudates on seed germination rate of *F. arundinacea* X-Axis, treated hours with roots exudates solution; Y-Axis, seed germination rate of *F. arundinacea* (A, *Justice*; B, *Commander*; C, Ayres; D, *Greenlabel*; E, *Arid3*; F, *Escalad*) in root exudates treatment

Table 2. Response index of *F. arundinacea* seed germination rate to Bermuda grass 'Baoding' root exudates (treatment in 72 h)

Species	Concentration of root exudates (mg·ml^{-1})	
	0.75	1.5
Justice	0.35c	-0.15c
Commander	0.37b	-0.19e
Ayres	0.35d	-0.23f
Greenlabel	0.39a	-0.11a
Arid3	0.30e	-0.13b
Escalad	0.24f	-0.16d

The allelopathic effects were specific to cultivar and tissue. For example, the leaf dry weight of *Commander* and *Justice* increased by 27% and 2% respectively at 0.75 mg·ml^{-1} Bermuda grass root exudates. While that in cultivar *Justice* and *Emerald* decreased by 49% and 3% at 1.50 mg·ml^{-1} root exudates concentration. Overall, the cultivar *Greenlabel* had lower allelopathic sensitivity to Bermuda grass root exudates and *Justice* cultivar was very sensitive. Besides, Bermuda grass root exudates had great influence on seedling roots. The 1.5 mg·ml^{-1} concentration decreased the seedling and root dry weight of *Commander* variety 13% or 28% respectively. The root exudates increased the seedling/root biomass than control.

Table 3 Biomass of *F. arundinacea* cultivars in dealing with root exudates of Bermuda grass 'Baoding'

Species	Root exudates conc. (mg·ml^{-1})	Seedling dry weight (g)	Root dry weight (g)	Ratio	Total dry weight (g)
Justice	0	0.71±0.04c	0.87±0.06a	0.82	1.58
	0.75	0.72±0.02bc	0.75±0.04bc	0.96	1.47
	1.50	0.36±0.02i	0.48±0.03g	0.75	0.84
Commander	0	0.58±0.03f	0.85±0.01ab	0.68	1.43
	0.75	0.74±0.03bc	0.83±0.01ab	0.89	1.57
	1.50	0.51±0.02h	0.61±0.05e	0.84	1.12
Ayres	0	0.68±0.02d	0.76±0.03bc	0.89	1.44
	0.75	0.76±0.02b	0.73±0.02bc	1.04	1.49
	1.50	0.55±0.01g	0.53±0.01f	1.04	1.88
Greenlabel	0	0.71±0.10bc	0.78±0.05b	0.91	1.49
	0.75	0.89±0.01a	0.76±0.05bc	1.17	1.65
	1.50	0.69±0.01cd	0.67±0.02d	1.03	1.36
Arid3	0	0.61±0.04e	065±0.02de	0.94	1.26
	0.75	0.66±0.01d	0.58±0.05f	1.14	1.24
	1.50	0.41±0.03h	0.40±0.04h	1.02	0.81
Escalad	0	0.84±0.04ab	0.87±0.05a	0.96	1.71
	0.75	0.87±0.02a	0.83±0.02ab	1.05	1.70
	1.50	0.64±0.01de	0.62±0.04e	1.03	1.26

*Data were means of three replicates. Means followed by the same letters in a column were not statistically different based on the least significance test at p = 0.05. The followings are same.

Table 4 Response index of *F. arundinacea* biomass to Bermuda grass 'Baoding' root exudates

Species	Concentration of root exudates (mg·ml^{-1})			
	0.75		1.50	
	Seedling	Root	Seedling	Root
Justice	0.02c	-0.14a	-0.49e	-0.44c
Commander	0.27a	-0.02a	-0.13b	-0.28b
Ayres	0.12b	-0.04a	-0.19bc	-0.29b
Greenlabel	0.24a	-0.02a	-0.03a	-0.14a
Arid3	0.09bc	-0.11a	-0.33d	-0.38bc
Escalad	0.04c	-0.05a	-0.24c	-0.29b

IV. Physiological indices of *F. arundinacea*

The Bermuda grass root exudates concentrations greatly influenced all physiological indices of *F. arundinacea* plants (Table 5). At 1.50 mg·ml^{-1} concentration most *F. arundinacea* cultivars were inhibited. Most *F. arundinacea* cultivars were inhibited at root exudates concentration of 1.50 mg·ml^{-1}, while, 0.75 mg·ml^{-1} root exudates were stimulatory. Bermuda grass root exudates at 1.50 mg·ml^{-1} concentration were more inhibitory to cvs. *Arid3* and *Justice* (with maximum combined absolute RI value of 1.04 and 1.58 respectively, but were less inhibitory to cv. *Greenlabel* (minimum combined effect of 0.31 only) (Table 6). Meanwhile, Bermuda grass root exudates also significantly affected the physiological index of MDA content (with maximum combined effect of 2.94 at 1.50 mg·ml^{-1} concentration) but less effect on other physiological indices (Table 5).

Table 5. Effects of Bermuda grass root exudates on physiological index of *F. arundinacea*

Species	Root exudates Con. ($mg \cdot ml^{-1}$)	MDA content ($umol \cdot g^{-1}$)	SSC ($g \cdot 100\ g^{-1}$)	Root activity ($mg \cdot g^{-1} \cdot h^{-1}$)	REL
	0	6.20±0.14de	10.73±0.19cd	5.08±0.10bc	0.62±0.05b
Justice	0.75	6.61±0.21de	11.12±0.79c	5.10±0.06b	0.57±0.02d
	1.50	12.01±0.95a	7.70±0.14h	3.81±0.35g	0.69±0.01a
	0	7.18±0.51cd	10.22±0.74de	4.48±0.11e	0.52±0.07f
Commander	0.75	4.79±0.11g	11.38±0.38bc	5.06±0.10bc	0.42±0.01h
	1.50	10.09±0.57b	9.41±0.32ef	4.41±0.53ef	0.53±0.01ef
	0	6.51±0.10de	11.40±0.85bc	4.74±0.11d	0.54±0.02e
Ayres	0.75	5.38±0.32f	12.82±0.32a	5.16±0.10ab	0.45±0.03gh
	1.50	9.13±0.55b	10.09±0.13de	4.32±0.06ef	0.55±0.01e
	0	6.68±0.31d	10.53±1.01d	4.60±0.21de	0.58±0.05cd
Greenlabel	0.75	4.22±0.17h	12.07±0.84ab	5.47±0.42a	0.43±0.01h
	1.50	7.68±0.05c	9.81±0.08e	4.43±0.12ef	0.55±0.02e
	0	7.54±0.27c	10.22±0.03de	4.99±0.05c	0.55±0.01e
Arid3	0.75	6.99±0.17cd	11.04±0.15c	5.25±0.39ab	0.48±0.04g
	1.50	12.19±0.18a	8.58±0.20g	4.06±0.26f	0.59±0.02c
	0	6.61±1.00d	10.78±1.01cd	5.10±0.50b	0.55±0.03e
Escalad	0.75	5.67±0.11ef	11.81±0.21b	5.32±0.09a	0.48±0.01g
	1.50	9.42±0.11b	9.24±0.13f	4.38±0.04ef	0.59±0.01bc

Plant allelochemicals are the secondary metabolites produced during the plant growth and development (28). According to the nature and biosynthetic pathway of allelochemicals, Rice (31) had divided them into 14 categories. Most studies showed the specificity of species and tissue to allelochemicals. For instance, the essential oil from *Thymus vulgaris*, *Origanum vulgare* and *Origanum dictamus* are rich in phenolic compounds representing 65.8%, 71.1%, and 78.0% of the total, respectively, while the essential oil from *Lavandula angustifolia Mill.* was rich in alcohols (58.8%) and esters (32.7%)(11). The allelochemicals of *Pinus massoniana* mainly consisted of α-dulcisol and γ-juniperene in roots, but benzaldehyde and Cis-2,6-dimethyl-2,6-octadiene in leaves (7). The root and shoot of wheat contained the same kinds of allelochemicals such as p-hydroxybenzoic acid, trans-coumaric acid and other 6 compounds, but their content in roots was higher than in shoot (34). The main chemical substances in the rhizosphere soil of Pear orchard were alkanes (38.49 % of the total) followed by esters and alcohols (9). In this study, the allelochemical components in Bermuda grass root exudates mainly consisted of ester (50.31%) and alkane (17.03%). Thus, due to the variations of allelopathic components and contents in tissues, organs and species had different allelopathic effects. Abu-Romman reported that the water extracts of leaves and flowers of *A. biebersteinii* were more suppressive to seed germination of *Hordeum spontaneum* than root and stem extracts (2). Therefore, well understanding of the allelochemical composition of each allelopathic donor would be necessary to know the allelopathy mechanism.

Table 6. Response index of *F. arundinacea* physiological index to Bermuda grass ‘Baoding’root

exudates at concentration of 0.75 or 1.50mg·ml^{-1}

Species	Concentration of root exudates (mg·ml^{-1})									
	0.75					1.50				
	MDA content (umol·g^{-1})	SSC (g·100 g^{-1})	Root activity (mg·g^{-1}·h^{-1})	REL	Combined effect *	MDA content (umol·g^{-1})	SSC (g·100 g^{-1})	Root activity (mg·g^{-1}·h^{-1})	REL	Combined effect
Justice	0.07a	0.04a	0.00b	-0.08a	0.19	0.94a	-0.28e	-0.25cd	0.11a	1.58
Commander	-0.33d	0.11a	0.13ab	-0.19bc	0.76	0.40c	-0.08ab	-0.02a	0.02bc	0.52
Ayres	-0.17c	0.12a	0.09ab	-0.17b	0.55	0.40c	-0.11bc	-0.09ab	0.02bc	0.62
Greenlabel	-0.37d	0.15a	0.19a	-0.26c	0.97	0.15d	-0.07a	-0.04ab	-0.05c	0.31
Arid3	-0.07b	0.08a	0.05b	-0.13ab	0.33	0.62b	-0.16d	-0.19c	0.07a	1.04
Escalad	-0.14c	0.10a	0.04b	-0.13ab	0.41	0.43c	-0.14cd	-0.14bc	0.07ab	0.78
Combined effect	1.15	0.6	0.5	0.96		2.94	0.84	0.73	0.34	

* Combined effect means sum of the absolute RI value of 4 physiological indices of one species (line) or those of 6 species of a physiological index (column)

GC-MS analysis showed that the major allelochemicals in Bermuda grass root exudates were esters, which are allelopathic. For example, dehydromatricaria ester (DME) from *Solidago altissima* L seriously affects the growth of rice variety, I_{50} for shoot and root growth was about 100 μg·g^{-1} (16). The methanol extracts of fruit peel of *Citrus junos* efficiently inhibited the growth of roots and hypocotyls of *Lactuca sativa* L., which mainly resulted from the high amount of abscisic acid-β-D-glucopyranosyl ester (ABA-GE) in *Citrus junos* (20). In our report here, the major ester substance in Bermuda grass root exudates was 3-Phenylpropyl 4-methylbenzoate in highest content (34.73%,of the total). Although no study on its allelopathic effects are reported, several papers displayed the p-hydroxybenzoic acid group might inhibit the proliferation of *Chlorella*, (39), and decrease the seed germination and dry shoot weight of wheat (37). Octadecanamide is another major compound (13.81% in total) in Bermuda grass root exudates. Matthew revealed that octadecanamide and some other fatty acid amides were toxic metabolites and present in grasses and microalgae (6). More attention to these allelochemicals is suggested in future to well understand the grass allelopathy.

The allelochemicals contents vary with plants variety, tissue and developmental stage. Liu (24) found that the humus soil from *Betula platyphylla* was inhibitory to seed germination and seedling growth to 8 of 11 tested medicinal plants. Thereafter, some of them were not recommended for interplanting in *B. platyphylla* forests. Similarly, the allelopathic effects of Bermuda grass root exudates were expressed as RI values: -0.11 and -0.23 for seed germination of cvs. G*reenlabel* and *Ayres*, -0.13 and -0.28 for seedling dry weight and root dry weight of *Commander*, and 1.58 and 0.31 for combined effects of 4 physiological indices of cvs. *Justice* and *Greenlabel* at 1.5 mg·ml^{-1} Bermuda grass root exudates, respectively.

Concentration of extracts or allelochemicals was another important factor in allelopathic effect. In our study, the comparable RI value for 0.75 and 1.5 mg•ml^{-1} concentration of the Bermuda grass root exudates were : 0.39 and -0.11 for cv. *Emerald* seed germination, -0.37 and 0.15, for cv. *Greenlabel* MDA content and 0.27 and -0.13 for cv. *Commander* seedling biomass, respectively. Clearly, the lower concentration of Bermuda grass root exudates stimulated the *F. arundinacea* seed germination and seedling growth but higher concentration was inhibitory. Also, some *F. arundinace* cultivars such as

Justice were more sensitive to the Bermuda grass root exudates, while, some others such as *Greenlabel* were insensitive. Therefore, screening a suitable *F. arundinace* cultivar for mix-sowing with Bermuda grass needs to determine an appropriate proportion is necessary. The similar performance was also reported in foxtail millet straw water extracts on maize growth (12) and soybean root extracts on seed germination and seeding growth of *Brassica juncea var. tumida* (38). Thus, proper understanding of the allellopathic effects among species or cultivars is necessary for developing their mixed-sowings.

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