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Allelopathic potential of aqueous extract of *Archidendron jiringa* (Jering) pods for weed control in the swamp paddy field

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Abstract The allelopathic potential of *Archidendron jiringa* (jering) pods to control weeds in swamp paddy field was investigated. The Aqueous extract of jering pods was first evaluated on the germination of paddy seeds in the laboratory. Then, field experiment was conducted to study the allelopathic effect of jering pod extracts on weeds and swamp paddy. The results showed that the aqueous extracts of jering pods inhibited the germination and the growth of radicles and plumules of paddy germination. The extracts showed allelochemical effects to inhibit the emergence of weeds in the swamp paddy plots, where the level of inhibition was stronger by increasing the concentration of jering pods extracts. Preemergence application of an aqueous extract of jering pods effectively controlled the number of population and the growth of narrow-leaf (grass and sedges) weeds, and the growth of broad-leaf weeds. The highest efficacy observed at the highest concentration of extract of 500 g/L, suppressed dry weight of narrow-leaf and broad-leaf weeds by 74.4 and 37.5 percent, respectively. As the weeds were suppressed, the growth and yield of swamp paddy were increased in the number of productive tillers, dry weight of biomass, and yield by 19.01, 42.61, and 43.54 percent, respectively.

Keywords: Allelochemicals, Allelopathy, Jering pods, Swamp paddy, Weed control

Introduction

Weeds always evolve in planting areas and inhibit the growth and yield of crops through the mechanism of competition and allelopathy (Duke, 2015, Gealy *et al*., 2014). Yield losses due to the presence of weeds can reach 30 – 50 % (Oerke, 2005; Folnovic, 2015). Therefore, it has been a common need in agricultural practices to control weeds with an appropriate method in order to reach the target of crop yield. The most worldwide method of weed control is using chemical herbicides (Duke, 2012, Owen, 2016). The use of herbicide developed worldwide and it has been a major input in the agricultural systems for both land clearing and weed control (Gealy *et al*., 2014; Heap, 2019).

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Continuous and excessive uses of herbicides may cause detrimental effects to the agricultural ecosystem and evolve resistant weeds (Powles and Preston, 2006; Powles, 2018). One way to overcome this problem is approaching the weed problems by natural management strategy, such as optimizing the potential of allelopathy from local resources (Bhadoria, 2011). This approach can be adopted by using crop residues as compost applied directly on the planting area or by extracting the allelochemicals and applied on the fields (Tabaglio *et al*., 2013; Arif *et al*., 2015).

Allelopathy is direct or indirect harmful or beneficial effects by one plant (including microorganisms) to another through the production of chemical compounds that escape into the environment (Cheng and Cheng, 2015). Recently, allelopathy is interpreted as negative (inhibitory) effects through the release chemical compounds which are known as allelochemicals (Inderjit *et al.*, 2006; Lou *et al*., 2016). Allelochemical compounds can also be produced from weeds and plants directly or through the decomposition of plant residues. Almost all parts of plants that can produce allelochemical compounds such as leaves, flowers, seeds, stems, and roots of the plants that are still alive or decaying (Weston and Duke, 2003). Various processes of releasing chemicals include exudates from the roots, decomposition, evaporation, and washing of plant organs. If one species of plants produces allelochemical compounds, then the sensitive species can be injured and died (Saxena, 2016). Allelochemicals may affect both the number of weed populations and the growth of weeds. In the concept of sustainable agriculture, using allelopathy from decomposing plant materials may function not only to control weeds naturally but also to supply some nutrition into the soil (Schulz *et al*., 2013; Cheng and Cheng, 2015).

Some important crops were reported to have allelopathic potential are sorghum (Cheema *et al*., 2004), rice (Wang *et al*., 2007), barley (Farhoudi and Lee, 2013), coffee fruit peels (Silva *et al*., 2013), rye straw (Tabaglio*et al*., 2013), wheat straw (Schulz *et al*., 2013), fruit bunch of palm-oil (Simarmata *et al*., 2015), and jering pods (Nurdjanah *et al*., 2015). Whereas, allelopathy that appears from some important weeds are jimson weed (Cai and Mu, 2012), Cogongrass (Hagan *et al*., 2013), Lily (Cheng and Xu, 2013), and switchgrass (An *et al*., 2013).

A plant named *Archidendron jiringa* (Jack) I.C. Nielson or *Pithecellobium jiringa* (Jack) Prain, *Pithecellobium lobatum* Benth. or *Zygia jiringa* (Jack) Kosterm are some botanical named of jering (Barceloux, 2009). It is commonly named as dogfruit, jering or jengkol (Indonesia and Malaysia), chaniang, luknieng, niangnok (Thailand), tangyin, and tanyeng-pen (Myanmar) which is native to Southeast Asia (Bunawan *el al*., 2013; Wiriadinata, 2016). It belongs to Fabaceae. Jering trees can reach 18-25 meters tall, grow upright, multi-branched with spreading crown, and have round woody stems with a grey glabrous bark (Bunawan *et al.*, 2013). Young jering beans are usually consumed raw, but mature seeds are prepared in several ways such as boiled, roasted, fried, and processed to make jering chips (Wiriadinata, 2016).

The pods of jering beans remaining in very abundant amounts are usually disposed of as waste, but research showed that they can be used as a source of organic materials. The current research showed an allelopathic potential of jering pods in paddy fields (Nurdjanah *et al*., 2015). Some chemical compounds that are contained in the dried pods can be aqueous extracted for using as allelochemicals compounds in agriculture. The research reported by Nurjanah *et al*. (2015) found that the application of 15 tons per ha of freshly jering pods on the paddy field inhibited the weeds and this evidence indicated the potency of using jering pods not only as soil amendments but also to control weeds.

The objectives were to examine the potential of water extraction of *Archidendron jiringa* (jering pods) with varying concentrations as organic herbicides evaluated on paddy germination in the laboratory, and then applied pre-planting on swamp paddy field to find the efficacy of the extracted compound on weeds and effectivity on growth and yield of swamp paddy.

Materials and methods

The research was conducted at the Laboratory of Agroecotechnology and Experimental Station of the University of Bengkulu, from January to July 2018. The first study evaluated the effect of the aqueous extract of *Archidendron jiringa* (jering) pods on paddy seeds germination. Fresh jering pods were first washed with tap water and air-dried at room temperature for 1 x 24 hours. Jering pods of 20, 40, 60, 80, and 100 grams in accordance with the concentration in the laboratory experiment were cut into small pieces with a size of 1 cm^3 and then soaked in 1 L of water for each treatment. The aliquot was filtered with a 0.5-mm sieve after 24 h soaked and stored at 4 C before used for the experiment. Ten paddy seeds were grown in petri-dishes using Whatman paper #1 as a growing media and watered with allelochemical extracts of jering pods at the concentration as described previously, and water without allelochemical compound used as controls. The experiment was arranged in a completely randomized design (CRD) with 5 replications. Data observed at 7 days after planting included percent of germination as described in equation 1 (Eq. 1), dry weight of plumules, and radicles. Data were subjected to analysis of variance (ANOVA) at 95 % and further separated with LSD test at 5 %.

$$Seed\ germination = \frac{\text{Number of planted seeds} - \text{Number of growth seeds}}{\text{Number of seed planted}} \text{ x } 100\ \% \text{..... Eq. 1}$$

The field experiment was arranged in a completely randomized design (CRD) with four replications. The treatments were water extract of jering pods at 100, 200, 300, 400, and 500 grams/L of water, and water without extracts used as controls. The protocol of extraction was similar as previously described in the laboratory experiment. Wooden tubs sized of 1 m x 1 m x 0.35 m (length x width x depth) were formed as a barrier of the experimental plot. The tubs were placed in the swamp-field area, filled with swamp-soil and arranged as described in the research design. The extract of the jering pods was sprayed on the soil surface as a pre-plant treatment at the spray volume of 400 L/ha. Three seedlings of paddy rice *var.* Surya that seeded in the pre-nursery were transplanted on the research plots with a planting distance of 20 cm x 20 cm. Paddy plants were maintained following rice cultivation standards. Thinning and replanting were carried out one week after transplanting. One vigor plant was kept in one planting hole. Fertilization was carried out in the second week by broadcast spreading of Urea, Phosphate, and Potassium fertilizers with doses of 250, 125, and 100 kg/ha, respectively. Insects and pests were controlled by spraying chlorpirypos and sipermetrin insecticides, and azoxystrobin and diphenoconazole fungicides at the recommended doses. Plants were irrigated following the system of rice intensification (SRI) technology. Harvesting was done at the age of 115 days after planting or approximately when 80% of the paddy grains turned yellow.

Data of five sample plants were selected as representations of 20 plants in a research plot. The variables observed were plant height and number of productive tillers of paddies at the age of 60 days after planting. Data collected at harvest time including grain yield of the paddy. Data of weeds were observed at 60 days after treatment include weed population and biomass. Data of weeds were separated between the narrow-leaf (grass and sedge families) and broad-leaf weeds. Paddy seeds and weed biomass were oven-dried at 70 C for 3 x 24 hours. Data were subjected to one way classification of analysis of variance (ANOVA) at 95 %, and further separated by Fisher's LSD test at 5 %. Allelopathy efficacy was accounted as absolute values as equation 2 (Eq. 2), growth and yield enhancement of paddy were calculated as Eq. 3, modified from the research article of Simarmata *et al*. (2018).

$$Allelopathy\ Efficacy = \frac{|\text{Weed Biomass (t)} - \text{Weed Biomass (c)}|}{\text{Weed Biomass (c)}} \text{ x } 100\ \% \text{ ..... Eq. 2}$$

$$Growth\ and\ Yield\ Enhancement = \frac{D(t) - D(c)}{D(c)} \text{ x } 100\ \% \text{..... Eq. 3}$$

Where, (t) is treatment, (c) is controlled, and (D) is data of growth or yield.

Results

Suppression of jering pod extracts on seed germination

Germination and growth of paddy seeds in petri-dishes were significantly affected by aqueous extract of jering pods (*A. jiringa*) (Table 1). The higher the concentration of the extracts, the greater the inhibition of germination and growth observed on the dry weight of plumules and radicles. The germination of untreated seeds were 88.8 %, while at the highest concentration of jering pod extract of 100 g/L, the germination was only 10.4 %. The suppression of germinations were 3.6, 11.7, 51.3, 71.1, and 88.3 % at the concentrations of 20, 40, 60, 80, and 100 g/L, respectively. Similarly, the suppression on the dried weight of plumules was 4.9, 15.6, 26.1, 28.7, and 30.6 %, respectively and the radicles were 61.5, 74.7, 82.3, 87.3, and 89.6 %, respectively. At the highest concentration of 100g/L, the radicle weightwas suppressed by 89.6 percent, while the plumule was only suppressed 30.6 % (Table 1).

Table 1. The effects of jering pod aqueous extract on seed germination and growth of paddy seeds

AEC [/1] (g/L)	**SG** [/2] (%)	**SSG** [/3] (%)	**DWP** [/4] (g/sprout)	**SDWP** [/5] (%)	**DWR** [/6] (g/sprout)	**SDWR** [/7] (%)
0	88.8 a	0	3.07 a	0	2.21 a	0
20	85.6 ab	3.6	2.92 a	4.9	0.85 b	61.5
40	78.4 b	11.7	2.59 b	15.6	0.56 bc	74.7
60	43.2 c	51.3	2.27 bc	26.1	0.39 c	82.3
80	25.6 d	71.1	2,19 c	28.7	0.28 c	87.3
100	10.4 e	88.3	2.13 c	30.6	0.23 c	89.6
	*	-	*	-	*	-

Notes: *= significant effects by ANOVA at 95 %, Numbers followed by the same letters in a column are not significantly different by LSD test at 5 %. [1]/AEC=Aqueous extract concentration; [2]/SG=Seed germination; [3]/SSG=Suppression of seed germination; [4]/DWP=Dry weight of plumule; [5]/SDWP= Suppression of dried weight of plumules; [6]/DWR=Dried weight of radicles; [7]/SDWR=Suppression of dried weight of radicles.

Efficacy of jering pod extracts on weed populations

Aqueous extracts of jering pods applied preemergence at several concentrations showed significant effects on the weeds population and growth which was observed in dry weight of narrow-leaf weeds (grasses and sedges), but no significant effect was observed on the population of broad-leaf weeds (Table 2). The higher the concentration of jering pod extracts, the more suppression was observed on the population of narrow-leaf weeds. The populations of narrow-leaf weeds at the end of the experiment were 88, 80, 74, 73, 61, and 29 individuals per meter^2 for the extracts of 0, 100, 200, 300, 400, and 500 g/L, respectively (Table 2). Similarly, the dry weight biomass of narrow-leaf weeds was also suppressed significantly by the jering pods extracts. The dry weight of narrow-leaf weeds were 156, 152, 118, 112, 90 and 40 g/m^2 with the extracts of 0, 100, 200, 300, 400, and 500 g/L, respectively.

Table 2. The effect of jering pod aqueous extract on weeds on the swamp paddy plots

AEC[/1] (g/L)	**PNLW**[/2] (number of weeds/m^2)	**PBLW**[/3] (number of weeds/m^2)	**TPW**[/4] (number of weeds/m^2)	**DWNLW**[/5] (g/m^2)	**DWBLW**[/6] (g/m^2)	**DWTW**[/7] (g/m^2)
0	88 a	18	106 a	156 a	56 a	212 a
100	80 a	15	95 b	152 a	54 a	206 a
200	74 a	18	92 b	118 b	45 ab	163 b
300	73 a	16	89 b	112 b	43 b	155 b
400	61 ab	16	77 c	90 c	36 b	126 c
500	29 b	17	46d	40 d	35 b	75 d
	*	ns	*	*	*	*

Notes: *= significant influences by ANOVA at 95 %, ns = not significant, Numbers followed by the same letters in a column are not significantly different by LSD test at 5 %. [1]/AEC=Aqueous extract concentration; [2]/PNLW=Population of narrow-leaf weeds; [3]/PBLW=Population of broad-leaf weeds; [4]/TPW=Total population of weeds; [5]/DWNLW=Dry weight of narrow-leaf weeds; [6]/DWBLW=Dry weight of broad-leaf weeds; [7]/DWTW=Dry weight of total weeds.

In contrast to the narrow-leaf weeds, the population number of broad-leaf weeds was not influenced, but the dry weight of biomass was suppressed by the extracts. The dry biomass weight of broad-leaf weeds was 56, 54, 45, 43, 36, and 35 g/m^2 for the concentrations of extracts of 0, 100, 200, 300, 400, and 500 g/L, respectively (Table 2).

The efficacy of jering pods extracts is based on the ability to inhibit weed population and weed growth which was observed as dry biomass weight (Table 3). The efficacy of jering pod extracts was observed on both the population and biomass of narrow-leaf weeds (grass and sedges). On the other hand, the efficacy of the broad-leaf weeds was only evidence on biomass. The concentration of 500 g/L, the efficacy on narrow-leaf population and biomass were 67 and 74.4 %, respectively. On the other hand, the efficacy on broad-leaf weeds was only indicated on dry biomass weight at the extract concentration of 500 g/L resulted in the biomass of broad-leaf weeds of 37.5 %.

Table 3. Efficacy of jering pod aqueous extract on weed populations and biomass in swamp paddy plots

AEC[/1]	**Efficacy on Weeds Population**		**Efficacy on Weed Biomass**	
(g/L)	NLW[/2](%)	BLW[/3](%)	NLW[/2] (%)	BLW[/3](%)
0	0	0	0	0
100	10.0	16.7	2.6	3.6
200	15.9	0	24.4	19.6
300	17.1	11.1	28.2	23.2
400	27.0	11.1	57.7	35.7
500	67.0	5.6	74.4	37.5

Notes: [1]/AEC=Aqueous extract concentration; [2]/NLW=Narrow leaf weeds; [3]/BLW=Broad leaf weeds.

Enhancement on growth and yield of paddy

The preemergence application of jering pods extracts that suppressed weed population and growth showed a significant effect to increase growth and yield of swamp paddy. The variables observed of productive tiller number, dried biomass weight, and yield which increased significantly, but plant height was not affected by the extracts (Table 4). The aqueous extract of jering pods increased the number of tillers of 17.60, 16.20, and 19.01 % with the extracts of 300, 400, and 500 kg/ha, respectively. These were also linear to increase the dry weight of biomass and yield which ranged from 35.49 to 42.61 % and 30.32 to 43.54% with concentrations of 200 and 500 g/L, respectively.

Table 4. The growth and yield of swamp paddy after pre-plant application of an aqueous extract of jering pods

AEC[/1] (g/L)	**PH[/2]** (cm)	**NPT[/3]** (# of tillers/ plant)	**INPT[/4]** (%)	**DWB[/5]** (g/plant)	**IWB[/6]** (%)	**GY[/7]** (g/plant)	**IGY[/8]** (%)
0	63.40	7.10 b	-	35.61 b	-	59.95 c	-
100	62.70	7.20 b	1.41	35.76 b	0.42	63.39 c	5.74
200	62.77	7.25 b	2.11	48.25 a	35.49	78.13 b	30.32
300	63.46	8.35 a	17.60	48.73 a	36.84	81.69 ab	36.26
400	63.57	8.25 a	16.20	49.58 a	39.23	85.26 a	42.22
500	64.13	8.75 a	19.01	51.40 a	42.61	86.05 a	43.54
	ns	*	-	*	-	*	-

Notes: * = significant effects by ANOVA at 95 %, ns: not significant, Numbers followed by the same letters in a column are not significantly different by LSD test at 5 %; [1]/AEC=Aqueous extract concentration; [2]/PH=Plant height; [3]/NPT=Number of productive tillers; [4]/INPT=Increased number of productive tillers; [5]/DWB=Dry weight of biomass; [6]/IDWB=Increased of the dry weight of Biomass; [7]/GW=Grain yield; [8]/IGY=Increased grain yield.

Discussion

Many plants have potential as sources of allelopathy both directly and indirectly through compost and extract of biomass (Weston, 2003). The abundant waste of *Archidendron jiringa* (jering) pods has been reported as a potential source of allelopathy (Nurjanah *et al*., 2015). The results of testing the extract as allelopathy in paddy seed germination showed the inhibition of germination and growth of seedlings. According to Cai and Mu (2012), the mechanisms of allelochemicals are most effective through the roots. Imbibition of water into the embryo along with allelochemicals initiated the germination process but the allelochemicals of jering pod extract inhibited the development of the embryo (Cheng and Cheng, 2015). Therefore, some seeds are still germinated but the growth of radicles would be injured. The same evidence was described from Table 1, where there was growth retardation in the paddy radicles in the seedling stage due to aqueous extract of jering pods. The highest inhibition on radicles reached 89.6 % at a concentration of 100 g/L, whereas on the plumules were only 30.6 %. The allelochemical molecules of jering pods are mostly like phenolic and jengcolate acids (Nurjanah *et al*., 2015), where these compounds may inhibit enzymes which was related to radicle growth in paddy embryo.

Agricultural land functions as a seed bank for weeds because thousands of dormant seeds are stored within the soil for a long time. In favorable circumstances, such as temperature, light, and water, the dormant weed seeds will germinate and grow (Bhadoria, 2011; and Simarmata *et al*., 2015). Soil preparation for planting will give the advantages for weed seed growing along with crops. Residues of some plants were reported to give allelopathy potential that may inhibit weed germination and growth (Simarmata *et al*., 2015). The application of jering pods extract on the paddy field inhibited the population and growth of narrow-leaf weeds. Inhibition was stronger by increasing the jering pod concentrations. Less germinated weeds indicated on weed population that observed with a jering pod concentration at 500 g/L. Aqueous extract of jering pods contained jengcolate and phenolate acids that function as allelochemicals inhibited not only germination but also the growth of narrow-leaf weed. However, the populations of the broad-leaf weeds were not influenced, but the growth of biomass was inhibited by the extracts. Jering pods as plant residues can function as a natural weed management strategy to control weeds through allelochemicals (An *et al*., 2013; Saxena *et al*., 2016).

According to Nurjanah *et al*. (2015), jering pods contain allelochemicals that inhibit the seed germination and growth of weeds. The mechanisms are inhibited the activity of enzymes in the embryo and damaged the permeability of cell membranes of radicles and plumules (Cai and Mu, 2012; Duke, 2015). The allelochemicals of cover crop residues affected the weed suppression and the microbial community in the soil (Lou *et al*., 2016). Simarmata *et al*. (2015) reported that incorporation of oil palm fruit bunches influenced the evolving weeds and caused the shifting of the weed population in the sweet corn field in the tropical agricultural ecosystem. Allelochemical compounds formed secondary metabolites that can be released into the rhizosphere through the decomposition of residues, evaporation or root exudates (Weston and Duke, 2003). The release of allelochemicals into the rhizosphere can further inhibit the germination and growth of weeds (Inderjit *et al*., 2006).

The decomposition of allelochemical compounds by microorganisms can occur approximately in 30 days, so that allelochemicals remained to inhibit weed seed germination (Tabaglio *et al*., 2013; Lou *et al.*, 2016). According to Li *et al*. (2010), the allelopathic compounds can inhibit the absorption of oxygen, respiration, cell division, and elongation. Allelochemical molecules from barley and sorghum can damage plant cell walls. If the cell wall is damaged and susceptible to leakage so seeds will be unable to germinate.

The aqueous extract of jering pods contains allelochemicals that inhibited the germination and growth of weeds, so that the competition between weeds and paddy was eliminated. The presence of weeds in the planting areas caused some negative influences through competition with crops that caused detrimental growth and yields (Duke, 2015; Folnovic, 2015). On the other circumstances, less weed population and growth in the planting areas would increase the availability of growing facilities, such as space and nutrients (Cheng and Cheng, 2015). These circumstances enhanced the growth and increased the yield of the main crops. The growth and yield variables were promoted by the application of jering pod extract as allelochemicals to control weeds. The higher concentration of jering pod extracts, the more yield of paddy was produced.

It is concluded that the aqueous extract of jering pods inhibited both the germination and the growth of paddy seedlings. However, the inhibition was not evidence on transplanted seedlings in the field. Preemergence application of the extracts in the paddy field indicated the allelochemical potential of jering pods which suppressed both populations and growth of narrow-leaf weeds (grass and sedges), but broad-leaf weeds were suppressed on the growth. The level of weed suppression became stronger by increasing the concentration of the extracts, where the highest efficacy in narrow-leaf and broad-leaf weeds were 74.4, and 37.5 %, respectively. The efficacy of aqueous extract of jering pods on weeds were consecutively stimulated the growth and yield of paddy. The highest impacts were found at the concentration of 500 g/L, which increased the number of the productive tillers, dry weight of biomass, and grain yield by19.01, 42.61, and 43.54 %, respectively.

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