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Effects of Mixed Application of Wood Vinegar and Herbicides on Weed Control, Yield and Quality of Rice (*Oryza sativa* L.)

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ABSTRACT The effect of mixed treatments of wood vinegar and sulfonylurea-based herbicides on weed control, yield and yield components, and quality of rice was investigated. Two herbicides were tested namely: imazosulfuron-ethyl + thiobencarb [ethyl-1-(2-chloroimidazo[1,2-*a*] pyridin-3-ylsulfonyl)-3-(4,6-dimethoxypyrimidin-2-yl) urea + *S*-4-chlorobenzyl diethyl(thiocarbamate)], and bensulfuron-methyl + butachlor [methyl α-[(4,6-dimethoxypyrimidin-2-ylcarbamoyl)sulfamoyl]-*o*-toluate + *N*-butoxymethyl-2-chloro-2',6'-diethylacetanilide]. The experiment was carried out in a randomized complete block design with 3 replications and 5 treatments. Treatments used were recommended (RH: 100%) and half-recommended (HRH: 50%) application rates of each herbicide. Half-recommended application rates were combined with 1 mL wood vinegar 500 mL water^{-1} (500) and 1mL wood vinegar 1000 mL water^{-1} (1000) wood vinegar. Plots for no herbicide treatments were also prepared and used as control.

Results showed that wood vinegar significantly increased efficacy of HRH in bensulfuron-methyl + butachlor while high efficacy was already obtained in HRH treatment of imazosulfuron-ethyl + thiobencarb. Wood vinegar did not improve the efficacy of imazosulfuron-ethyl + thiobencarb but improved rice yield. Significantly similar rice yields were obtained in the HRH + 1000 WV and RH treatments of both herbicides. There were no significant variations in the yield components among the treatments; however, differences in yield can be attributed to the variations in the spikelet number and ripening ratio. Data on rice quality analysis did not show clear trend on the effects of the treatments on grain appearance and nutritional quality.

Keywords : herbicide, rice, rice yield, weed control, wood vinegar

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Kim *et al.* (2000) investigated the activity of wood vinegar as foliar or contact herbicide. The study showed that foliar application of wood vinegar exhibited herbicidal activity against *Echinochloa crus-galli* at different growth stages though there was no observed inhibition effect when the wood vinegar was soil-applied. In related studies, herbicidal activity of acetic acid, which is the main active component of wood vinegar, has also been tried. Household and industrial vinegar at 5 and 20% acetic acid concentration, respectively, have been shown to be a useful broad-spectrum herbicide (Chinery, 2001). Other studies showed that vinegar is a potential inexpensive herbicide by spot treatment in organic agriculture (Radhakrishnan *et al.*, 2002), an effective weed control by basal application for in-row weed management in corn and soybean (Coffman *et al.*, 2005) and by foliar application for control of broadleaves (Webber *et al.*, 2005).

Wood vinegar has been found to greatly accelerate growth, shoot and root activity and nutrient uptake of rice plant (Ichikawa and Ota, 1982; Tsuzuki *et al.*, 1989), sugarcane (Uddin *et al.*, 1994), mushroom (Ohta and Zhang, 1994; Yoshimura *et al.*, 1995) and vegetable (Mu *et al.*, 2003), and promoted root growth and photosynthesis in sweet potato (Du *et al.*, 1998), and sucrose phosphate synthase in melon (Du *et al.*, 1998). Studies have also shown that use of material rich in dissolved organic carbon can affect herbicidal degradation, sorption, mobility and efficacy (Huang and Lee, 2001; Gigliotti *et al.*, 2005; Singh, 2003; Pullicino *et al.*, 2004; Cox *et al.*, 2006). Wood vinegar may affect the efficacy of herbicides in ways dissolved organic matter

(DOM) does.

Considering the large dissolved organic carbon content of wood vinegar, its strong fertilizing effect that promotes vigorous growth and root activity of young seedlings, and its ability to retard germination and radicle growth of germinating seeds, it may possibly increase the absorption and translocation of sulfonylurea-based herbicides in the plants and thereby increase the efficacy and phytotoxicity of the herbicides. Thus, it is the objective of this study to investigate the effects of wood vinegar and reduced dosages of sulfonylurea-based herbicides in rice production.

MATERIALS AND METHODS

The experiment was conducted in 2005 at the experimental field of Agricultural Research & Extension Services in Chilgok, Kyungpook. Rice variety Junambyeo was provided by the Rural Development Administration (RDA), Kyungbook Province while wood vinegar was obtained from the Korean Forest Research Institute (KFRI). All management practices in rice cultivation recommended by RDA were employed.

Rice seeds were sterilized for 24 hours, pre-germinated in 1~2 mm tap water in the dark at 30℃ and then 130 g of germinated seeds were sown in seedling tray (58×28×3 cm). Thirty-day old rice seedlings were manually transplanted with planting distance (30×14 cm) on May 20, 2005. The experiment was laid out in a randomized complete block design with three replications. The size of experimental plot was 20 m^2. Each plot was fertilized with N-P_2O_5-K_2O (11-5.5-4.8 kg $10a^{-1}$) as basal application: 50% N, 100% P, 70% K; topdressing at tillering stage: 25% N; and at panicle initiation stage: 25% N, 30% K.

Two granular sulfonylurea-based herbicides were tested and applied 15 days after rice transplanting namely: imazosulfuron-ethyl + thiobencarb [ethyl-1-(2-chloroimidazo[1,2-*a*]pyridin-3-ylsulfonyl)-3-(4,6-dimethoxypyrimidin-2-yl)urea + *S*-4-chlorobenzyl diethyl(thiocarbamate)], and bensulfuron-methyl + butachlor [methyl α-[(4,6-dimethoxypyrimidin-2-ylcarbamoyl)sulfamoyl]-*o*-toluate + *N*-butoxymethyl-2-chloro-2',6'-diethylacetanilide]. Herbicide application was done within 15 days after transplanting. Treatments used were recommended application rate (RH), half-recommended application rate (HRH), HRH plus 1 mL wood vinegar 500 mL $water^{-1}$ (HRH + 500 WV) and HRH plus 1 mL wood vinegar 1000 mL $water^{-1}$ (HRH + 1000 WV). The plot has a water depth of 3 cm (0.6 m^3). Hence, 500 and 1000 wood vinegar treatments received 1.2 L and 0.6L of wood vinegar, respectively. Untreated plots were used as control.

Parameters investigated were herbicide's efficacy, yield and yield components (panicle number, panicle length, spikelets per panicle, ripening ratio and 1000-grain weight); white grain protein and amylose contents, alkali digestion and palatability. Weeds were collected in a 0.5×0.5 m quadrat per plot 30 to 40 days after herbicide treatment. The weeds were then oven-dried for 72 hours at 60℃ and dry weights were recorded. Rice yield was measured by harvesting 100 hills per plot. The harvested grains were threshed, sun-dried and weighed.

Rice grain quality characteristics such as head, broken, chalky, damaged, colored and cracked grains were analyzed using grain analyzer (Cervitec 1625 Grain Inspector, Foss Tecator, Sweden). Ninety percent hulled rice grains were used to determine food value (protein and amylose contents) and palatability. Food value was measured using whole grain analyzer (Foss Infratec 1241 Grain Analyzer, Sweden) and palatability using Toyo taste meter (TOYO MB-90A, Japan). Alkali digestion value was determined using six grains of white rice immersed in 1.7% KOH solution in shallow containers and allowed to stand for 23 hours at 30℃ (Little, *et al.*, 1958). Alkali digestion values were obtained by comparing the spreading of the soaked grains to that of check samples of known behavior on a scale of 1 (not spreading) to 7 (perfect spreading).

Data were analyzed using analysis of variance (ANOVA) procedure (SAS Institute, Inc., Cary, NC, USA) and the least significant differences between treatments means were obtained using Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Effects of wood vinegar on the efficacy of the herbicides against paddy weeds

The effects of wood vinegar in enhancing efficacy of

two granular sulfonylurea-based herbicides that are commonly used in Korea were investigated. Table 1 summarized the types and functions of the herbicides used. The herbicides mainly affect protein and fatty acid synthesis in the target plants.

Table 2 showed the efficacy of mixture of wood vinegar and herbicides against annual (*Echinochloa crus-galli* (L.), *Monochoria vaginalis* (Burm. F.), *Aneilema keisak* Hassk., *Ludwigia prostrata*) and perennial (*Eleocharis kuroguwai* Ohwi.) weeds. The HRH treatment of imazosulfuron-ethyl + thiobencarb showed a remarkably high efficacy already that made wood vinegar ineffective in increasing its efficacy. For bensulfuron-methyl + butachlor, efficacy against *E. crus-galli* increased from HRH alone (78.7%) to HRH + 500 WV (100%) and HRH + 1000 WV (97.4%). In the case of *A. keisak* Hassk., efficacy increased from HRH alone (74.4%) to HRH + 500 WV (100%) and HRH + 1000 WV (89.1%). Total efficacy showed that only bensulfuron-methyl + butachlor increased efficacy from HRH alone (84.6%) to HRH + 500 WV (100%) and HRH + 1000 WV (97.9%). These results showed that wood vinegar was effective only in increasing efficacy of half-recommended application rate of bensulfuron-methyl + butachlor for control of paddy weeds in rice production.

Wood vinegar contains more than 200 kinds of organic compounds mainly composed of 12 kinds of organic acids, 13 kinds of phenol, 19 kinds of carbonyl, and 9 kinds of alcohol (Kim *et al.*, 2001) which can all act as growth

Table 1. Type and mode of action of the active ingredients (AI) in the herbicides.

Herbicide/AI	Type (% Content)	Mode of action
Imazosulfuron-ethyl	sulfonylurea (0.25%)	• inhibits branched-chain amino acid biosynthesis
Bensulfun-ethyl	sulfonylurea (0.17%)	• inhibits branched-chain amino acid biosynthesis
Thiobencarb	thiocarbamate (5.0%)	• inhibits fatty acid biosynthesis
Butachlor	α-chloroacetamide (2.5%)	• inhibits protein biosynthesis and acetyl CoA-relating sites, and oleic acid incorporation into a non-lipid (non-soluble cell wall) fraction

Sources: Reviews by Wakabayashi and Boger, 2004, and Usui, 2001.

Table 2. Efficacy of mixture of wood vinegar and sulfonylurea-based herbicides in control of paddy weeds in rice production.

Herbicide	HAR†	WV‡	Annual Weeds												Perennial weeds			Total		
			E. crus-galli (L.)			*M. vaginalis* (Burm. F.)			*A. keisak* Hassk.			*L. prostrata*			*E. kuroguwai* Ohwi					
			NP§ ($p\,m^{-2}$)	DW↓ ($g\,m^{-2}$)	E↘ (%)	NP ($p\,m^{-2}$)	DW ($g\,m^{-2}$)	E (%)	NP ($p\,m^{-2}$)	DW ($g\,m^{-2}$)	E (%)	NP ($p\,m^{-2}$)	DW ($g\,m^{-2}$)	E (%)	NP ($p\,m^{-2}$)	DW ($g\,m^{-2}$)	E (%)	NP ($p\,m^{-2}$)	DW ($g\,m^{-2}$)	E (%)
Imazo-sulfuron-ethyl+ Thiobencarb	1x[1]	-	0.0	0.0b[3]	100.0	0.0	0.0b	100.0	0.0	0.0a	100.0	0.0	0.0b	100.0	0.0	0.0b	100.0	0.0	0.0b	100.0
	1/2x	-	1.3	2.6b	97.6	0.0	0.0b	100.0	0.0	0.0a	100.0	0.0	0.0b	100.0	0.0	0.0b	100.0	1.3	2.6b	98.3
	1/2x	500[2]	0.0	0.0b	100.0	0.0	0.0b	100.0	0.0	0.0a	100.0	0.0	0.0b	100.0	0.0	0.0b	100.0	0.0	0.0b	100.0
	1/2x	1000	0.0	0.0b	100.0	0.0	0.0b	100.0	0.0	0.0a	100.0	0.0	0.0b	100.0	0.0	0.0b	100.0	0.0	0.0b	100.0
Bensulfuron-methyl+ Butachlor	1x	-	0.0	0.0b	100.0	0.0	0.0b	100.0	0.0	0.0a	100.0	0.0	0.0b	100.0	0.0	0.0b	100.0	0.0	0.0b	100.0
	1/2x	-	4.0	22.5ab	78.7	0.0	0.0b	100.0	2.7	1.0a	74.4	0.0	0.0b	100.0	0.0	0.0b	100.0	6.7	23.4ab	84.6
	1/2x	500	0.0	0.0b	100.0	0.0	0.0b	100.0	0.0	0.0a	100.0	0.0	0.0b	100.0	0.0	0.0b	100.0	0.0	0.0b	100.0
	1/2x	1000	1.3	2.8b	97.4	0.0	0.0b	100.0	1.3	0.4a	89.7	0.0	0.0b	100.0	0.0	0.0b	100.0	2.7	3.2b	97.9
Control	-	-	11.0	105.2a		15.0	28.2a	-	5.0	3.9a	-	3.0	3.5a	-	11.0	11.8a	-	45.0	152.5a	-

†HAR = Herbicide application rate; ‡WV = Wood vinegar; §NP = Number of plant, ↓DW = Dry weight, ↘E = Efficacy
[1]1X = Recommended application rate, 2X = Half recommended application rate
[2]500 = (1 ml wood vinegar / 500 ml water), 1000 = (1 ml wood vinegar / 1000 ml water)
[3]The same letters in each column are not significantly different at 5% level DMRT.

regulating herbicides on the germinating seeds. Its most potent component is acetic acid that can kill germinating seeds by destroying cell membranes and causing rapid desiccation of the plant tissues (Mu *et al.*, 2003). These organic compounds could have helped break the natural barriers and defense mechanism of the growing weeds that make them susceptible to attacks of the herbicides.

Wood vinegar may also affect the properties and behavior of the chemical herbicides in the soil system because it contains large amount of organic compounds. Wood vinegar may affect the efficacy of herbicides in ways dissolved organic matter (DOM) does. Studies have shown that dissolved organic matter (DOM) originating from different organic waste materials affects the sorption-desorption of pesticide in soil (Gigliotti *et al.*, 2005). Reports showed that DOM may reduce herbicide sorption through stable DOM-herbicide interactions (Businelli, 1997) or by competing with herbicide molecules for sorption sites on the soil surface (Lee *et al.*, 1990). However, it may also enhance herbicide sorption if the DOM sorbed on the soil particles provides additional sites for pesticide sorption (Gigliotti *et al.*, 2005).

Effects on rice yield and yield components

Table 3 showed the effects of mixture wood vinegar and herbicides on the yield and yield components of rice. Both herbicides obtained higher rice yield in HRH + 1000 WV treatments compared to their respective RH treatments. A more evident increase was recorded in HRH + 1000 WV bensulfuron-methyl + butachlor.

In case of yield components, all parameters obtained significantly similar values except for significantly lower ripening ratio in HRH bensulfuron-methyl + butachlor and a slightly lower value in the 1000-grain weight of HRH plus wood vinegar treatments of imazosulfuron-ethyl + thiobencarb. The ripening ratio obviously caused the lower rice yield in HRH bensulfuron-methyl + butachlor while spikelet number can be said to have caused the lower rice yield in imazosulfuron-ethyl + thiobencarb. A significantly lower ripening ratio was obtained in the HRH treatment of BSB compared to the other treatments. The highest ripening ratio was obtained in HRH + 500 (74.6%) followed by HRH + 1000 (71.9%). In imazosulfuron-ethyl + thiobencarb, a non-significantly lower spikelet number in HRH (118.0) compared to HRH + 500 (127.1) followed by HRH + 000 (129.9) was observed.

It could also be noticed that HRH + 1000 WV obtained higher yield compared to HRH + 500 WV even though higher efficacy in weed control was more evident in the latter. The yield components also showed that panicle and spikelet numbers were better in HRH + 1000 WV of both herbicides compared to HRH + 500 WV treatment. These results showed that rice seedlings performed well at lower wood vinegar concentration.

Table 3. Efficacy of mixture of wood vinegar and sulfonylurea-based herbicides on yield and yield components of rice.

Herbicide application rate	Wood vinegar (volume)	Panicle length (cm)		Panicle number		Spikelet Number		Ripening ratio (%)		1000-grain weight (g)		Yield (kg $10a^{-1}$)	
		IET[1]	BMB[2]	IET	BMB	IET	BMB	IET	BMB	IET	BMB	IET	BMB
Recommended	-	25.8a[3]	13.6a	32.7a	15.0a	126.1a	146.1a	65.3a	69.6ab	24.9a	24.1a	709.2a	717.7a
Half-Recommended	-	25.0a	13.2a	32.5a	14.1a	118.0a	143.8a	73.4a	61.3b	24.9a	24.5a	658.6ab	685.9ab
Half-Recommended	500	26.9a	13.8a	31.3ab	14.3a	127.9a	130.1a	74.6a	74.6a	24.8ab	24.2a	684.9ab	681.4ab
Half-Recommended	1000	24.8a	14.6a	28.5ab	15.3a	129.1a	141.2a	74.7a	71.9a	24.3bc	24.3a	709.7a	735.2a
Control	-	27.2a	14.4a	27.2b	14.4a	120.6a	120.6a	70.7a	70.7ab	24.2c	24.2a	613.6b	613.6b

[1]IET = imazosulfuron-ethyl + thiobencarb, [2]BMB = besulfuron-methyl + butachlor
[3]The same letters in each column are not significantly different at 5% level DMRT.

Table 4. Efficacy of mixture of wood vinegar and sulfonylurea-based herbicides on the appearance quality of rice grain.

Herbicide application rate	Wood vinegar (volume)	head		broken		chalky		damaged		colored		cracked	
		IET[1]	BMB[2]	IET	BMB	IET	BMB	IET	BMB	IET	BMB	IET	BMB
		%											
Recommended	-	93.3[3]	95.9a	4.4a	2.3b	1.0a	1.0a	1.2a	0.7b	0.2a	0.1a	8.2b	9.4c
Half-Recommended	-	93.2a	94.2ab	4.0a	3.1b	1.6a	1.8a	1.0a	0.8ab	0.1a	0.2a	11.4a	12.9a
Half-Recommended	500	92.9a	95.3a	4.4a	2.7b	1.6a	1.0a	1.0a	1.0ab	0.1a	0.1a	11.0a	11.5ab
Half-Recommended	1000	92.0a	94.5a	5.8a	2.7b	1.5a	1.6a	0.5a	1.2a	0.2a	0.1a	10.4ab	9.9c
Control	-	92.2a	92.2b	5.1a	5.1a	1.8a	1.8a	0.7a	0.7ab	0.3a	0.3a	10.6a	10.6bc

[1]IET = imazosulfuron-ethyl + thiobencarb, [2]BMB = besulfuron-methyl + butachlor
[3]The same letters in each column are not significantly different at 5% level DMRT.

Table 5. Efficacy of mixture of wood vinegar and sulfonylurea-based herbicides on the nutritional quality of rice.

Herbicide application rate	Wood vinegar (volume)	Protein content (%)		Amylose Content (%)		Palatability (Toyo meter)		Alkali digestion value (KOH 1~7)	
		IET[1]	BMB[2]	IET	BMB	IET	BMB	IET	BMB
Recommended	-	6.4b[3]	6.5c	17.6a	17.2a	80.7ab	79.8a	5.2ab	4.7b
Half-Recommended	-	6.6b	6.8ab	17.5a	16.9a	81.3a	72.3a	5.6a	5.1ab
Half-Recommended	500	6.5b	6.6bc	17.6a	17.1a	79.8abc	81.3a	5.2ab	5.0ab
Half-Recommended	1000	6.6b	6.8abc	17.5a	17.0a	78.4bc	80.4a	4.9b	5.0ab
Control	-	7.0a	7.0a	17.2a	17.2a	77.7c	77.7ab	5.7a	5.7a

[1]IET = imazosulfuron-ethyl + thiobencarb, [2]BMB = besulfuron-methyl + butachlor
[3]The same letters in each column are not significantly different at 5% level DMRT.

Effects on grain appearance and nutritional quality

Table 4 presented the result of grain appearance analysis. No significant differences were observed in the grain appearance quality of imazosulfuron-ethyl + thiobencarb except for cracked grains which was lowest in RH treatment. In the case of bensulfuron-methyl + butachlor, damaged and cracked grains were highest and lowest, respectively, in HRH + 1000 WV.

The grain nutritional quality was also analyzed to check the effects of the treatments on this parameter. Data showed (Table 5) that HRH plus wood vinegar treatments of bensulfuron-methyl + butachlor obtained relatively lower protein and amylose contents but higher palatability values compared to the other treatments. Higher protein content was obtained in the HRH treatment but palatability value was also significantly lower compared to the other treatments. Grain quality is an intrinsic genetic characteristic of rice plant that seldom responds to cultural practices. This probably explains the not so different variation on the grain quality values.

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