Research Article

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Effects of carbonized rice hull and wood charcoal mixed with pyroligneous acid on the yield, and antioxidant and nutritional quality of rice

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Abstract: The effects of mixture of rice hull charcoal and pyroligneous acid (MRPA) and mixture of wood charcoal and pyroligneous acid (MWPA) with reduced rate of chemical fertilizer on the yield, and antioxidant and nutritional quality of rice were investigated. Results showed that RF (Recommended N-P-K fertilizer application = 110-55-48 kg ha^{-1}) generally had higher agronomic and yield components than MWPA and MRPA treatments while MWPA was more effective in improving the yield of rice than MRPA. The total phenolic compounds and 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical electron-donating ability were improved at higher application rate of MWPA while xanthine oxidase (XO) inhibition was improved at lower MWPA. In the case of nutritional quality of rice, total amylose content increased while lipid content decreased at lower MWPA. Fatty acid contents were generally high at the combined treatments of organic material and chemical fertilizer than at chemical fertilizer alone. Furthermore, the results revealed that MWPA was more appropriate to use than MRPA in increasing both the antioxidant property and nutritional quality of rice.

Key words: Carbonized rice hull, charcoal, pyroligneous acid, rice yield

Introduction

Environmental pollution and proper disposal of organic agricultural wastes have prompted studies on developing technologies that will reduce these problems. In the process of charcoal making, for example, emission of large amount of gas to the atmosphere is avoided by trapping the gas to make a condensate called pyroligneous acid or smoke vinegar. Moreover, organic by-products of agricultural produce that would just otherwise be wasted are now effectively recycled and used in agricultural productivity. One such by-product is rice hull, which is now carbonized and used as soil conditioner.

Combined application of charcoal and pyroligneous acid has long been shown to significantly accelerate growth, shoot and root activity, and nutrient uptake in rice (Ichikawa and Ota 1982; Tsuzuki et al. 1989; Son et al. 2003; Lee et al. 2007). Unfortunately, there have been no studies yet regarding combined application of carbonized rice hull with pyroligneous acid.

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Recently, there have been reports on the beneficial effects of application of organic materials in increasing the phytochemical and antioxidant contents of oats and rice (Dimberg et al. 2005; Na et al. 2007). Moreover, combined application of organic materials and reduced dose of chemical fertilizer has been shown to be beneficial for soil nutrition and crop yield (Worthington 1998), and nutritional quality of rice (Rico et al. 2007; Saha et al. 2007; Kang et al. 2008).

In the present study, the effects of combined application of either mixture of carbonized rice hull and pyroligneous acid (MRPA) or mixture of wood charcoal and pyroligneous acid (MWPA) with reduced dose of fertilizer on the antioxidant and nutritional quality of rice were investigated.

Materials and methods

The experiment was conducted at the Agricultural Research and Extension Services in Chilgok, Kyungbuk, Korea. The rice variety 'Ilpumbeo' was provided by the Rural Development Administration (RDA), Kyungbuk, Korea, while MRPA and MWPA (4 charcoal:1 pyroligneous acid) were obtained from the Korean Ministry of Agriculture and Forestry. The pyroligneous acid was prepared from a liquid condensate extracted between 80 to 120 °C during the carbonization process (charcoal making) of Korean oak tree (*Quercus* sp.). The condensate was aged for 3 months and the thick liquid was collected. The same process was repeated before the commercial quality wood vinegar was collected. The physico-chemical properties of MRPA and MWPA showed that the organic matter and nitrogen contents of MWPA (53.94% and 0.33%, respectively) were higher than those of MRPA (41.80% and 0.25%, respectively), and pH of MRPA (9.82) was lower than that of MWPA (10.90) (Table 1).

Rice seeds were pre-germinated for 48 h in tap water in the dark at 30 °C and germinated seeds were sown in a seedling tray (58 cm × 28 cm × 3 cm). Thirty-day-old seedlings were machine-transplanted with planting distance of 30 cm × 14 cm. Other management practices recommended by the RDA in rice cultivation were employed. Rice grains harvested from 100 hills per plot were threshed, sun-dried, and 90% hulled to obtain the brown rice.

Table 1. Some properties of organic materials used.

	MWPA§	**MRPA**§
pH	10.90	9.82
OM (%)	53.94	41.80
N (%)	0.33	0.25
OC (%)	31.29	24.19
C:N	43.45	53.76
EC (dS m^{-1})	2.34	1.01
P_2O_5 (%)	0.17	0.22
K ($cmol^+ kg^{-1}$)	0.65	0.49
Ca ($cmol^+ kg^{-1}$)	5.75	5.02
Mg ($cmol^+ kg^{-1}$)	3.29	2.98

§MWPA = mixture of wood charcoal and pyroligneous acid; §MRPA = mixture of rice hull charcoal and pyroligneous acid.

The experiment was laid out in a complete randomized block design with 9 treatments and 3 replications for 2 years. The experimental field consisted of sub-plots of 5 m × 4 m (20 m^2). The treatments were recommended N-P-K fertilizer application (RF = 110-55-48 kg ha^{-1}) used as control, 100% MRPA (2400 kg ha^{-1}), 100% MWPA (3000 kg ha^{-1}), and 75% and 50% of each organic waste combined with 50% RF and 25% RF.

Measurement of growth characteristics and yield components

Growth characters (plants height, tiller number, and chlorophyll content), yield components (panicle number, panicle length, spikelets per panicle, ripening ratio, and 1000-grain weight), and yield were measured. Growth characters were measured at MTS and HS. Chlorophyll content was determined using a chlorophyll meter (SPAD-502, Minolta, Ramsey, NJ, USA) in the mid portion of the last well-developed leaf. Ten plants per replicate were used for each parameter measured.

Antioxidant analysis

Brown rice was used for analyses of total phenol and electron donating capacity. A rice sample (4 g) was dissolved in 40 mL of 70% ethanol by continuous shaking for 24 h at 40 °C. The supernatant was used for the analysis. The electron donating capacity was analyzed using a method modified from the procedure described by Yen and Chen (1995). The reaction mixture contained 0.5 mL of 0.05 mM DPPH and 0.01 mL of brown rice supernatant. The solution was allowed to react for 30 min at room temperature and then absorbance reading at 517 nm was recorded.

Total phenolic compounds were determined using the procedure described by Zielinski and Kozlowska (2000). Brown rice supernatant (0.25 mL) was mixed with 0.25 mL of 50% Folin-Ciocalteu (Sigma Co.), 0.5 mL of 10% Na_2CO_3, and 2 mL of distilled water. The solution was allowed to stand for 25 min at room temperature and then centrifuged at 5000 rpm for 10 min. The supernatant liquid was collected and absorbance reading at 725 nm was recorded. Gallic acid (100 to 500 µg mL^{-1}) was used for the standard curve.

Xanthine oxidase (XO; EC 1232) inhibitory activity was measured using a UV-visible spectrophotometer based on the modified procedure of Noro et al. (1993). Absorbance of brown rice extracts was spectrophotometrically measured at 292 nm to estimate liberated uric acid. The blank sample contained the assay mixture without XO. The inhibition activity of XO was calculated using the following equation:

Inhibition of XO activity (%) = $(1 - A_{sample}/A_{control}) \times 100$.

Nutritional quality analysis

Rice starch lipids, known to exist as inclusion complexes with amylose in the starch granules, were measured according to the method of Takahashi and Seib (1988) with a slight modification. Two grams of brown rice sample was placed into a centrifuge tube, and then 25 mL of 75% *n*-propanol solution was added. The mixture was boiled in a water bath for 2 h at 100 °C. Extracted lipids were saponified by the method of Ruibal-Mendieta et al. (2004), and the methyl esters of fatty acids were extracted with *n*-hexane for analysis. The gas chromatograph (6890 plus, Hewlett Packard Co. Palo Alto, CA, USA) was equipped with a DB-225 capillary column (30 m × 0.25 mm, 0.25 µm film thickness) coupled to a mass spectrometer (JMS700, JEOL, Tokyo, Japan). The column was held at 140 °C for 1 min, then programmed to 200 °C at 5 °C 5 min^{-1} and increased to 10 °C min^{-1} to 230 °C, and finally held for 10 min. Helium was used as the carrier gas at a flow rate of 1 mL min^{-1} (ionizing energy; 70 eV).

Fatty acid analysis was done following the procedure of Ruibal-Mendieta et al. (2004). Brown rice sample was methylated by reacting with methanolic potassium hydroxide and analyzed for fatty acid using GC-MS (GC-MS: HP 6890 series, Hewlett Packard, Japan) equipped with a DB-225 column (30 m × 0.25 mm × 0.25 µm). The injector temperature was 250 °C while the column temperature was 140 °C for 2 min and gradually increased to 200 °C at 5 °C min^{-1} and finally increased to 220 °C at 10 °C min^{-1}. The injection volume was 1 µL injected at a flow rate of 1 mL min^{-1}.

For the amylose contents, analysis was done by adding 2 N NaOH to the sample and then neutralized by adding 1/9 N acetic acid followed by the addition of iodine-potassium iodine reagent (1% I_2 in 10% KI). Absorbances of the samples were scanned using a UV/visible spectrometer (DU 800 series, Beckman Coulter Inc., Fullerton, CA, USA). The amylose contents of rice starches were determined as the absorbances at 680 nm based on the standard curve of a pure amylose (Sigma, St. Louis, MO, USA).

Statistical analysis

Two-year pooled data were statistically analyzed for significance by the GLM procedure using SAS. Fisher's least significant tests were conducted to compare treatment means when ANOVA showed a significant level for differences among treatments.

Results

Effect on the agronomic character and yield

At the maximum tillering stage, RF resulted in the highest plant height (44.3 cm) and chlorophyll content (38.8 spad unit, respectively) which were similar to those recorded in 50% MWPA + 50% RF (42.15 cm and 37.3 spad unit, respectively) (Table 2). The highest tiller number was observed in 100% MWPA + 25% RF and it was similar to those obtained

Table 2. Effects of different mixtures of organic materials and chemical fertilizer on plant height (PH), tiller number (TN), and chlorophyll content (CC) at maximum tillering and heading stages of rice.

Treatment[§]	Maximum tillering stage			Heading stage		
	PH (cm)	TN	CC (SPAD unit)	PH (cm)	TN	CC (SPAD unit)
50% MWPA+50% RF	42.15[†] ab[‡]	21.8 abc	37.3 ab	99.7 a	14.6 a	33.8 a
75% MWPA+25% RF	39.53 bc	21.3 abc	36.5 bc	96.2 abc	13.1 ab	33.5 a
100% MWPA+25% RF	38.93 bc	26.0 a	35.4 cde	96.8 ab	13.8 ab	32.7 a
100% MWPA	35.93 c	19.9 bc	35.4 cde	93.8 bcd	13.0 ab	28.6 cd
50% MRPA+50%RF	36.12 c	18.5 c	35.4 cde	90.8 d	12.2 ab	33.4 a
75% MRPA +25% RF	35.85 c	18.6 c	34.1 de	91.7 d	12.6 ab	32.3 ab
100% MRPA +25% RF	37.97 bc	19.9 bc	35.9 bcd	91.2 d	12.3 ab	31.1 abc
100% MRPA	37.35 bc	20.0 bc	33.9 e	93.2 bcd	11.6 b	27.8 d
RF	44.30 a	25.0 ab	38.8 a	92.8 cd	12.1 ab	29.7 bcd

[§]100% MWPA = 3,000 kg ha^{-1}, 100% MRPA = 2,400 kg ha^{-1}, RF = 110-55-48 kg ha^{-1}.
[†]All values are means of 30 measurements in 3 replicates.
[‡]Same letters are not significantly different at $P < 0.05$ level by LSD.

in RF, 50% MWPA + 50% RF and 75% MWPA + 25% RF (25.0, 21.8, 21.3, respectively). At the heading stage, 50% MWPA + 50% RF and 100% MWPA + 25% RF resulted in plant height higher (99.7 and 96.8 cm, respectively) than RF (92.8 cm). Similar tiller number values were recorded in all treatments except for 50% MWPA + 50% RF and 100% MRPA. In the case of chlorophyll content, 50% MWPA + 50% RF, 75% MWPA + 25% RF, 100% MWPA + 25% RF and 50% MRPA + 50% RF had higher values (33.8, 33.5, 32.7, 33.4, and 33.4 spad unit, respectively) than RF (29.7 spad unit).

RF gave the highest panicle number (14.5), which was similar to those recorded in 50% MWPA + 50% RF, 75% MWPA + 25% RF and 100% MWPA + 25% RF (12.9, 13.8, 12.3, respectively). On the other hand, these 3 treatments recorded ripening ratios (78.9, 77.0, and 77.3, respectively) higher than that observed in RF (70.7). In the case of 1000-grain weight, 50% MWPA + 50% RF had the highest value (27.2 g), which was similar to those obtained in the rest of the treatments except for 100% MRPA (24.9 g). There were no significant differences in the panicle length across treatments. The MRPA treatments generally resulted in low panicle number values (9.0 to 10.4). RF gave the highest yield (6573 kg ha^{-1}). Only 50% MWPA + 50% RF and 100% MWPA + 25% RF recorded yields (6240 and 6021 kg ha^{-1}) that were similar to that of RF (Table 3). On the other hand, the MRPA treatments generally resulted in low yields (4067-4759 kg ha^{-1}).

Effect on the antioxidant property

Table 4 shows that 100% MWPA + 25% RF gave the highest total phenolic compounds (20.02 mg GAE g^{-1} DW) and 100% MRPA the lowest (14.32). The same trend was also observed in the DPPH analysis. Moreover, 100% MWPA + 25% RF had the highest DPPH radical scavenging activity (44.45%) and 100% MRPA the lowest (14.04%). The standards used for DPPH analysis were vitamins C and E, and butylated hydroxytoluene. These standards gave very high DPPH radical scavenging activity (90.38%-91.36%). Higher values in these analyses indicated higher antioxidant activity. In the case of xanthine oxidase

Table 3. Effects of different mixtures of organic materials and chemical fertilizer on the yield components of rice.

Treatment§	Panicle length (cm)	Panicle number	Ripening ratio (%)	1000 Grain weight (g)	Yield (kg ha^{-1})
50% MWPA+50% RF	21.2†	12.9 ab‡	78.9 ab	27.2 a	6,240 ab
75% MWPA+25% RF	20.3	13.8 ab	77.0 abc	26.9 a	5,689 bc
100% MWPA+25% RF	20.2	12.3 abc	77.3 ab	26.4 ab	6,021 ab
100% MWPA	20.8	11.5 bcd	72.5 bcd	25.7 ab	5,127 cd
50% MRPA+50%RF	20.6	10.2 cde	74.7 abcd	26.7 ab	4,416 de
75% MRPA +25% RF	21.4	9.0 e	75.5 abcd	26.7 ab	4,759 de
100% MRPA +25% RF	21.1	10.4 cde	74.6 abcd	25.8 ab	4,617 de
100% MRPA	19.8	9.8 de	70.1 d	24.9 b	4,067 e
RF	21.6	14.5 a	70.7 cd	25.7 ab	6,573 a

§100% MWPA = 3000 kg ha^{-1}, 100% MRPA = 2400 kg ha^{-1}, RF = 110-55-48 kg ha^{-1}.
†All values are means of 30 measurements in 3 replicates.
‡Same letters are not significantly different at $P < 0.05$ level by LSD.

Table 4. Effects of different mixture organic materials and chemical fertilizer on the total phenolic compound, DPPH radical scavenging activity, and xanthine oxidase inhibition of brown rice.

Treatment§	Total phenolic compounds (mg GAE g^{-1} DW)	DPPH radical scavenging activity (%)	Xanthine oxidase inhibition (%)
Vitamin C	-	91.36 ± 0.03 a†	-
Vitamin E	-	90.38 ± 0.10 b	-
Butylated hydroxytoluene	-	90.55 ± 0.10 ab	-
100% MWPA	18.78 ± 0.08† b‡	32.16 ± 1.65 f	14.39 ± 1.54 e
100% MWPA+25% RF	20.02 ± 0.12 a	44.45 ± 0.53 c	14.26 ± 0.24 e
75% MWPA+25% RF	18.27 ± 0.02 f	36.78 ± 1.06 d	11.97 ± 0.52 f
50% MWPA+50% RF	18.57 ± 0.03 e	30.90 ± 0.73 g	44.79 ± 1.47 a
100% MRPA	14.32 ± 0.02 h	14.04 ± 1.81 i	19.78 ± 1.47 d
100% MRPA+25% RF	16.81 ± 0.06 g	30.81 ± 0.64 g	18.86 ± 0.12 d
75% MRPA+25% RF	18.63 ± 0.05 d	28.07 ± 0.29 h	25.10 ± 0.56 c
50% MRPA+50% RF	18.70 ± 0.07 c	31.21 ± 1.19 g	43.31 ± 2.11 b
RF	18.27 ± 0.06 f	34.25 ± 0.98 e	25.59 ± 0.17 c

§100% MWPA = 3000 kg ha^{-1}, 100% MRPA = 2400 kg ha^{-1}, RF = 110-55-48 kg ha^{-1}.
†All values are means of 3 replicates.
‡Same letters are not significantly different at $P < 0.05$ level by LSD.

inhibition, 50% MWPA + 50% RF gave the highest value (44.79%) followed by 50% MRPA + 50% RF (43.31%).

Effect on the nutritional quality

The result of starch and total lipid analyses are presented in Table 5; 50% MWPA + 50% RF and 50% MRPA + 50% RF resulted in higher starch amylose content than RF, while 100% MWPA and 100% MRPA gave higher lipid content (15.18 and 14.38 mg g^{-1}, respectively) than RF (13.6 mg g^{-1}). The other treatments recorded higher lipid content (13.95-14.98 mg g^{-1}) than the RF as well.

Fatty acid composition analysis was conducted to determine the effects of the treatment on myristic ($C_{14:0}$), palmitic ($C_{16:0}$), stearic ($C_{18:0}$), palmitoleic ($C_{16:1}$), oleic ($C_{18:1}$), linoleic ($C_{18:2}$), and linolenic ($C_{18:3}$) acids (Table 6). The 100% MWPA + 25% RF treatment gave the highest myristic (0.34%) and palmitic acid (18.9%) contents in brown rice. Moreover, 50% MWPA + 25% RF had the highest stearic, oleic, and linolenic acid contents (1.33%, 36.46%, and 1.19%, respectively). It also gave very high palmitoeic acid content (18.84%).

Discussion

The higher agronomic character and yield in RF was quite expected since RF contained high amounts of readily available nutrients needed by the plants. MRPA treatments had a decreasing trend in the values in panicle number and ripening ratio compared to those observed in the MWPA treatments. This trend resulted in lower yields recorded in the MRPA treatments compared to those obtained in the MWPA treatments. This could also be attributed to the generally high nutrient components like organic matter, organic carbon, nitrogen content, and exchangeable cations in MWPA than in MRPA.

The higher application rate of MWPA and lower dose of chemical fertilizer could increase the antioxidant quality in terms of radical scavenging activity of rice compared with RF. This observation was also reported in other studies (Rico et al. 2007; Kang et al. 2008). The higher antioxidant quality of rice in MWPA than MRPA could also be attributed to the higher nitrogen and organic matter contents of MWPA. However, higher application rate of both MWPA and MRPA at lower dose of chemical did not

Table 5. Effects of different mixture organic materials and chemical fertilizer on the starch amylose and lipid contents of brown rice.

Treatment[§]	Starch amylose (%)	Lipid content (mg g^{-1})
100% MWPA	0.2231 ± 0.01[†] de[‡]	15.18 ± 0.01 a
100% MWPA+25% RF	0.2329 ± 0.01 cd	13.95 ± 0.01 g
75% MWPA+25% RF	0.2061 ± 0.01 f	14.27 ± 0.02 e
50% MWPA+50% RF	0.2773 ± 0.00 a	14.98 ± 0.02 b
100% MRPA	0.2281 ± 0.01 de	14.38 ± 0.20 d
100% MRPA+25% RF	0.2160 ± 0.02 ef	14.27 ± 0.01 e
75% MRPA+25% RF	0.2294 ± 0.01 d	14.14 ± 0.02 f
50% MRPA+50% RF	0.2560 ± 0.00 b	14.39 ± 0.01 c
RF	0.2428 ± 0.00 c	13.16 ± 0.01 h

[§]100% MWPA = 3000 kg ha^{-1}, 100% MRPA = 2400 kg ha^{-1}, RF = 110-55-48 kg ha^{-1}.
[†]All values are means of 3 replicates.
[‡]Same letters are not significantly different at P < 0.05 level by LSD.

Table 6. Effects of different mixture organic materials and chemical fertilizer on the fatty acid contents (%) of brown rice.

Treatment§	Myristic acid ($C_{14:0}$)	Palmitic acid ($C_{16:0}$)	Stearic acid ($C_{18:0}$)	Palmitoleic acid ($C_{16:1}$)	Oleic acid ($C_{18:1}$)	Linoleic acid ($C_{18:2}$)	Linolenic acid ($C_{18:3}$)
100% MWPA	0.29 ± 0.02† c‡	18.16 ± 0.14 b	1.10 ± 0.11 c	18.16 ± 0.14 bc	35.66 ± 0.23 bc	43.63 ± 0.09 e	1.15 ± 0.01 ab
100% MWPA+25% RF	0.34 ± 0.01 a	18.90 ± 1.14 a	1.23 ± 0.07 ab	18.90 ± 1.14 a	35.43 ± 0.20 bc	42.87 ± 1.10 f	1.09 ± 0.14 bc
75% MWPA+25% RF	0.29 ± 0.03 c	17.75 ± 0.22 bc	1.24 ± 0.02 ab	17.75 ± 0.22 ab	35.73 ± 0.10 b	43.76 ± 0.14 de	1.09 ± 0.05 bc
50% MWPA+50% RF	0.33 ± 0.01 ab	16.84 ± 0.60 e	1.33 ± 0.06 a	18.84 ± 0.60 a	36.46 ± 0.23 a	43.70 ± 0.76 e	1.19 ± 0.05 a
100% MRPA	0.29 ± 0.02 c	17.90 ± 0.33 bc	1.29 ± 0.02 c	17.90 ± 0.33 c	34.25 ± 0.21 e	45.21 ± 0.18 a	0.93 ± 0.10 d
100% MRPA+25% RF	0.33 ± 0.02 ab	17.46 ± 0.57 cd	1.20 ± 0.15 ab	17.46 ± 0.57 ab	35.42 ± 0.66 bc	44.37 ± 0.42 bcd	1.06 ± 0.15 c
75% MRPA+25% RF	0.32 ± 0.00 b	17.46 ± 0.11 cd	1.32 ± 0.17 bc	17.46 ± 0.11 bc	34.81 ± 0.30 d	44.91 ± 0.04 ab	1.05 ± 0.08 c
50% MRPA+50% RF	0.33 ± 0.00 ab	17.02 ± 0.44 de	1.23 ± 0.06 ab	17.02 ± 0.44 ab	35.40 ± 0.07 c	44.83 ± 0.41 abc	1.05 ± 0.07 c
RF	0.32 ± 0.17 b	17.39 ± 0.41 cde	1.28 ± 0.05 ab	17.39 ± 0.41 ab	35.65 ± 0.24 bc	44.19 ± 0.17 cde	1.05 ± 0.04 c

§100% MWPA = 3000 kg ha^{-1}, 100% MRPA = 2400 kg ha^{-1}, RF = 110-55-48 kg ha^{-1}.

†All values are means of 3 replicates.

‡Same letters are not significantly different at $P < 0.05$ level by LSD.

improve the xanthine oxidase activity. Inhibition of XO has been proposed as a mechanism for improving cardiovascular health (Dawson and Walters 2006; Higgins et al. 2009). The contradicting results in the antioxidant quality and xanthine oxidase activity deserve further studies.

It is thought that rice quality is affected by the environmental conditions and cultural practices during growth aside from characteristics influenced by genetic control. Brandt and Molgaard (2001) noted that plants grown organically produce more secondary metabolites for the defense mechanism of the plants against pest infestation. The significant decrease in chemical fertilizer could have promoted production of secondary metabolites; thus, an increased antioxidant activity was observed in the reduced chemical fertilizer treatment. Several studies showed that use of organic materials and organic farming system can possibly increase the antioxidant levels of strawberries (Wang and Lin 2003), peach and pears (Carbonaro et al. 2002), and vegetables (Ren et al. 2001).

The treatments did not show a clear trend on the effect on the fatty acid composition. However, the fatty acid composition was in agreement with those previously reported (Cho et al. 2006; Kang et al. 2008), indicating that it was not negatively affected by the treatments. Other studies showed that combined application of organic materials and reduced dose of chemical fertilizer did not result in significant decrease in fatty acid content of rice (Lee et al. 2004; Kang et al. 2008). A similar study on fatty acid content in red raspberry seed oil did not show significant effects of application times and application rate of nitrogen fertilizer and organic manure (Gercekcioglu et al. 2007).

Application of MWPA and MRPA at lower dose of chemical fertilizer did not compromise the nutritional quality of rice. Kang et al. (2008) made similar observations on the effect of combined treatment of rice bran and reduced dose of chemical fertilizer on rice. The efficacy of the organic material used could be attributed to the porous surface of charcoal, which improves the permeability of soil by water, and its property to adhere and prevent leaching of fertilizer (Glaser et al. 2002). It could be also due to the more favorable chemical properties of MWPA compared to MRPA.

In general, the study revealed that MWPA was more effective in improving agronomic characters, panicle number, ripening ratio and yield of rice than MRPA. Furthermore, both MWPA and MRPA gave higher antioxidant quality than RF, but MWPA was more effective than MRPA in increasing the antioxidant quality. The treatments affected the total lipid content more than the starch content. Fatty acid content of rice was in acceptable amounts and was not negatively affected by the treatments. Furthermore, application of MWPA is more appropriate in improving both the antioxidant and nutritional quality of rice.

References

Brandt K, Molgaard JP (2001) Organic agriculture: does it enhance or reduce the nutritional value of plant foods? J Sci Food Agric 81: 924-931.

Carbonaro M, Mattera M, Nicoli S, Bergamo P, Cappelloni M (2002) Modulation of antioxidant compounds in organic vs conventional fruit (peach, *Prunus persica* L., and pear, *Pyrus communis* L.). J Agric Food Chem 50: 5458-5462.

Cho KS, Kim HJ, Moon SM, Kang JH, Lee YS (2006) Optimization of one-step extraction/methylation method for analysis of fatty acid composition in brown rice. Korean J Crop Sci 51: 89-94.

Dawson J, Walters M (2006) Uric acid and xanthine oxidase: future therapeutic targets in the prevention of cardiovascular disease? British J Clinical Pharma 62: 633.

Dimberg LH, Gissen C, Nilsson J (2005) Phenolic compounds in oat grains (*Avena sativa* L.) grown in conventional and organic systems. Ambio 34: 4-5.

Gercekcioglu R, Yilmaz N, Bayrak OF, Sahin F (2007) Variation in fatty acid comoposition of 'Tulameen' red raspberry seed oil by the application of nitrogen fertilizers and organic manure. Int J Nat Eng Sci 1: 59-64.

Glaser B, Lehmann J, Zech W (2002) Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – a review. Biol Fertil Soils 35: 219-230.

Higgins P, Dawson J, Walters M (2009) The potential for xanthine oxidase inhibition in the prevention and treatment of cardiosvascular and cerebrovascular disease. Cardiovasc Psychia Neuro 2009: 1-9.

Ichikawa T, Ota Y (1982) Plant growth-regulating activity of pyroligneous acid I. Effect of pyroligneous acid on the growth of rice seedlings. Japanese J Crop Sci 51: 14-17.

Kang MY, Kim JH, Heo HK, Cho SS, Esguerra MQ, Rico CM, Son TK, Lee SC (2008) Effects of combined application of rice bran and chemical fertilizer on the phytochemical contents of rice. Korean J Crop Sci 53: 65-71.

Lee HJ, Yi CH, Lee SH, Chung JH (2004) Reducing fertilizer application and rice growth and yield mapping by variable rate treatment in paddy fields. In: Proceedings of International Crop Science Congress on New directions for a diverse planet (Eds. Fischer T et al.), Brisbane, Australia.

Lee JJ, Shon TK, Furuya T, Jin ID, Chung IK, Lee SC (2007) Effect of different kinds of environmental friendly materials on the growth of rice. J Fac Agr Kyushu Univ 52: 39-42.

Na GS, Lee SK, Kim SY (2007) Antioxidative effects and quality characteristics of the rice cultivated by organic farming and ordinary farming. J Korean Soc Appl Biol Chem 50: 36-41.

Noro T, Oda Y, Miyase T, Ueno A (1993) Inhibitors of xanthine oxidase from the flower and buds of Daphne Genkwa. Chem Pharm Bull 31: 3982-3990.

Ren H, Endo H, Hayashi T (2001) The superiority of organically cultivated vegetables to general ones regarding antimutagenic activities. Mutation Res 496: 83-88.

Rico CM, Bhuiyan MKI, Mintah LO, Shin DI, Chung IK, Son TK, Lee SC (2007) Effects of biofertilizer on the quality and antioxidant property of rice (*Oryza sativa* L.). Korean J Crop Sci 52: 1-7.

Ruibal-Mendieta NL, Dekeyser A, Delacroix DL, Mingnolet E, Larondelle Y, Meurens M (2004) The oleate/palmitate ratio allows the distinction between whole meals of spelt (*Triticum spleta* L.) and winter wheat (*T. aestivum* L.). J Cereal Sci 39: 413-415.

Saha S, Pandey AK, Gopinath KA, Bhattacharaya R, Kundu S, Gupta HS (2007) Nutritional quality of organic rice grown on organic composts. Agron Sust Dev 27: 223-229.

Son TK, Lee JE, Kim SK, Lee SC (2003) Effect of mixture of charcoal and pyroligneous acid applied to the soil at different fertilizer levels on the growth and yield of rice. Japanese J Crop Sci 72: 345-349.

Takahashi S, Seib PA (1988) Paste and gel properties of prime corn and wheat starches with and without native lipids. Cereal Chem 65: 474-483.

Tsuzuki E, Wakiyama Y, Eto H, Handa H (1989) Effect of pyroligneous acid and mixture of charcoal with pyroligneous acid on the growth and yield of rice plant. Japanese J Crop Sci 589: 592-597.

Wang S, Lin H (2003) Compost as a soil supplement increases the level of antioxidant compounds and oxygen radical absorbing capacity in strawberries. J Agric Food Chem 51: 6844-6850.

Worthington V (1998) Effect of agricultural methods on nutritional quality: a comparison of organic with conventional crops. Altern Ther Health Med 4: 58-69.

Yen GC, Chen HY (1995) Antioxidant activity of various tea extracts in relation to their antimutagenicity of various tea extracts in relation to their antimutagenicity. J Agric Food Chem 43: 27-32.

Zielinski H, Kozlowska H (2000) Antioxidant activity and total phenolics in selected cereal grains and their different morphological fractions. J Agric Food Chem 48: 2008-2016.