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Wood vinegar and fermented bioextracts: Natural products to enhance growth and yield of tomato (*Solanum lycopersicum* L.)

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ABSTRACT

Wood vinegar (WV) or pyroligneous acid and fermented bioextracts (FB) from plants or animal residues, have been used in agriculture in an attempt to reduce the dependence on the use of chemicals. The objective of this study was to investigate the effects of WV and FB on growth and yield of tomato, cv. *Delta*, in pot and field experiments. The study was undertaken between December 2008 and May 2009. A split-plot design with four replications was used. The main-plot treatments comprised high and low application rates of chemical fertilizer, while the sub-plot treatments were water, diluted FB (1:500 by volume), WV (1:800 by volume) applied as soil drench and foliar spray, in nine treatment combinations which included untreated control treatment. The foliar spray and soil drench treatments were applied at 10 day-intervals after transplanting (30 days after emergence). The results of two experiments were in agreement, with rates of chemical fertilizer clearly increasing the yield of tomato ($P < 0.01$). The application of WV and FB, alone or in combination, showed small increases in total plant dry weight, fruit number, fruit fresh weight and fruit dry weight, but significantly enhanced total soluble solutes of tomato fruit ($P < 0.01$). Wood vinegar and fermented bioextracts had similar effects on the growth and yield of tomato. However, when used in combination, there was an additive effect. Wood vinegar and fermented bioextracts can be used in the form foliar sprays or as a soil drench, there being no significantly difference in the effects found in any traits, between the methods of application.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is consumed as a vegetable and used as a raw material for processed products. It is an important vegetable crop and rich in vitamin A and C that are useful to human health (Grierson and Kader, 1986). High inputs of chemical fertilizers and pesticides considerably increase production costs, and these inputs might have potential negative effects on the environment and human health. This is resulting in researchers and producers seeking alternative techniques for tomato production.

Bioextracts or fermented bio-extracts (FB), is defined as fermented product obtained from aerobic and/or anaerobic fermentation of either plant or animal waste, supplemented with an appropriate carbon source (Tancho, 2008). It has been of interest, especially in organic agriculture, as the application of FB has been demonstrated to significantly increase growth of vegetable crops such as onion, pea, and sweet corn (Daly and Stewart, 1999), radish (El-Tarabily et al., 2003), cowpea (Kamla et al., 2008) and tomato (Aung and Flick, 1980; Sangakkara and Higa, 1994; Xu et al., 2000).

Wood vinegar (WV) or pyroligneous acid, is a by-product of charcoal burning. Smoke from the charcoal kiln is channeled into a long pipe to allow condensation of the smoke. The liquid condensed smoke is subsequently left to stand for three months of natural purification. Three layers result, light oil on top, translucent brown WV at the middle and the thick wood tar at the bottom. Only translucent brown WV is used as raw WV. Wood vinegar consists of more than 200 water soluble compounds comprising organic acids, phenolic, alkane, alcohol and ester compounds (Wei et al., 2010). Wood vinegar has many uses, including as an odor remover, animal feed additive and agricultural uses such as an insect repellent, and soil or foliar fertilizer (Mohan et al., 2006). When used as priming agent, WV promotes radicle and hypocotyls growth of watercress and chrysanthemum (Mu et al., 2003) and increases the survival rate of scarlet sage and zinnia when mixed with charcoal and barnyard manure as a potting mix media (Kadota and Niimi, 2004).

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In fire prone habitats in the regions with a Mediterranean-type vegetation, such as in Western Australia, California and South Africa, smoke in various forms has been extensively studied, as it promotes germination in many plant species (Baxter et al., 1995; Brown and Van Staden, 1997; Brown et al., 2003; Commander et al., 2008; Dixon and Roche, 1995). In 2004, biologically active butenolide compound (3-methyl-2H-furo[2,3-c]pyran-2-one) was successfully isolated from burnt cellulose and plant-derived smoke (Flematti et al., 2004; Van Staden et al., 2004), later referred to as karrikinolide and karrikins, which is a new family of plant growth regulators (Chiwocha et al., 2009; Dixon et al., 2009; Flematti et al., 2009). Research on the use of smoke for enhancing crop growth has shown that smoke-water promotes seedling development of maize, tomato, okra, bean (Van Staden et al., 2006) and rice (Kulkarni et al., 2006).

Smoke-water foliar spray has been reported to promote seedling growth (Kulkarni et al., 2007) and yield of tomato under greenhouse experiment (Kulkarni et al., 2008). However, the application of smoke in the form of WV, in combination of FB, has not been well researched in tomato. In this study, the efficacy of these two natural products on growth and yield of tomato c.v. *Delta* was investigated when applied as foliar spray and soil drench in pot and field experiments. Two fertilizer application rates were used in an attempt to elucidate whether WV and FB can partially substitute the use of chemical fertilizer.

2. Materials and methods

2.1. Experimental design

A pot experiment and a field experiment were conducted at the same time, between December 2008 and May 2009. The pot experiment was undertaken in an open air environment at the Field Crop Research Station of Khon Kaen University, Khon Kaen province, Thailand (latitude 16°28′N, longitude 102°48′E, 200 m asl), while the field experiment was carried out in a farmer's field in the same general locality. During the course of the study, climatic conditions were generally dry, with mean maximum and minimum temperatures of 33.8 °C and 22.2 °C, respectively, daily pan evaporation of between 0.4 and 9.8 mm, average relative humidity of 77.9% and solar radiation of 18.8 MJ m^{-2} d^{-1}.

A split-plot experiment arranged in a randomized complete block design with four replications was used. Two fertilizer rates, a high rate (recommended dose: 82.1, 35.4, 79.5, 2.25 kg N-P-K-Ca/ha; Department of Agriculture, Ministry of Agriculture and Cooperatives, Bangkok, Thailand) and a low rate (half of recommended rate: 41.1, 17.7, 39.7, 1.13 kg N-P-K-Ca/ha) were assigned to the main plots, while there were nine sub-plot treatments: (1) untreated control; (2) soil drench with water; (3) foliar spray with water; (4) soil drench with FB; (5) foliar spray with FB; (6) soil drench with WV; (7) foliar spray with WV; (8) soil drench with WV combined with FB, and (9) foliar spray with WV combined with FB. Fertilizer sources were compound fertilizer grades 15-15-15, 13-13-21 and $Ca(NO_3)_2$ (15-0-0).

2.2. Seed source

Seeds of processing tomato (cv. *Delta*) were purchased from a commercial source (East-West Seed Co Ltd., Nonthaburi, Thailand). The variety is a commercial F_1 hybrid.

2.3. Wood vinegar and fermented bio-extract analyses

Wood vinegar was obtained from Energy Ashram, Appropriate Technology Association, Thailand. It was made from eucalyptus wood using Iwatae charcoal kiln. Fermented bioextract was prepared by thorough mixing of ground-golden apple snail (*Pomacea canaliculata* (Lamarck)), a major rice pest in Asia (Halwart, 1994), as the starting raw material, with molasses in the ratio of 4:1 by weight. Microbial inoculum, Por Dor 2, developed by Department of Land Development in Thailand was added to enhance the fermentation process. The mixture was subsequently kept in a tightly closed vessel and left to stand at room temperature for 30 days. Components of WV were analyzed using GC–MS Model Agilent 6890. Standard methods were used to measure N, P, K, pH, organic matter and electrical conductivity (EC) in WV and FB. The components of WV and FB are shown in Table 1.

Table 1
Components of wood vinegar (WV) and fermented bio-extracts (FB).

Parameter	WV	FB
pH	3.09	7.15
EC (mS/cm)	3.27	23.46
N (%)	0.03	0.17
P (%)	0.10	0.04
K (%)	0.01	0.31
Ca (%)	0.01	0.19
Acetic acid (%)	30.39	–
Propanoic acid (%)	6.08	–
Phenol (%)	3.75	–
Phenol, 2-methoxy- (%)	12.31	–
Thiirane, methyl- (%)	26.96	–
Pyridine, 3-methyl- (%)	0.73	–
2-Furancarboxaldehyde (%)	6.39	–
Ethanone (%)	1.19	–
2-Methoxy-4-methylphenol (%)	6.27	–
3,6,9,12,15-Pentaoxanonadecan-l-ol (%)	2.38	–

2.4. Pot experiment

The soil used was a sandy soil in the Yasothon series (Yt; fine-loamy, siliceous, isohypothermic, Oxic Paleustults), with a texture comprising sand (93.9%), silt (4.2%) and clay (1.9%). The chemical properties include pH 6.6, 0.7% organic matter and 0.04% total N. Macro nutrients comprise 22 ppm of available P (Bray II method), 62 ppm of extractable K and 430 ppm of Ca.

The plastic pots used in the study were 27 cm in diameter and 30 cm in height and were laid out with spacing 50 cm × 50 cm Each pot was filled by soil to within 10 cm of the top, using 10.5 kg dry soil to create a uniform bulk density. Each treatment consisted of four pots in a replicate. Lime was applied to all pots before planting at a rate of 1.44 g/pot. For the high fertilizer rate, N-P-K fertilizers (15-15-15) at a rate of 0.65 g N/pot, 1.84 g P/pot and 3.37 g K/pot were applied prior to planting, whereas the same fertilizers at half of these rates were applied to the low rate treatment pots.

Seeds were germinated in plug trays in a peat moss medium, with water being applied daily. At 30 days after emergence (DAE), uniform seedlings were transplanted into pots, with one seedling per pot, after which water was applied to field capacity. The water applied to individual pots was maintained uniformly at field capacity until harvest. Water applied to individual plots was determined by the crop water requirement and surface evaporation, which were calculated following the methods described by Doorenbos and Pruitt (1992) and Singh and Russell (1981), respectively.

In the high fertilizer treatments, calcium nitrate ($Ca(NO_3)_2$) as a source of nitrogen and calcium, was applied at a rate of 1.4 g N/pot and 1.4 g Ca/pot at 14 days after transplanting (DAT). N-P-K fertilizer (15-15-15) at rates of 0.65 g N/pot, 1.84 g P/pot and 3.37 g K/pot were applied at 21 DAT, and N-P-K fertilizer (13-13-21) at rates of 0.65 g N/pot, 1.84 g P/pot and 3.37 g K/pot were applied at 40 DAT. In the low fertilizer treatments, half these amounts of fertilizers were applied.

At 10, 20, 30 and 40 DAT, WV and FB concentrates were diluted with water to 1:800 (v/v) and 1:500 (v/v), respectively, and then were applied as foliar spray (following growth stages at rates of 9.4, 12.5, 14.1 and 15.6 ml/plant, respectively) and as a soil drench (based on calculations to achieve field capacity) on four occasions after transplanting, at 10 day-intervals. For the water treatments, the same amount of as for FB or WV was applied by spraying the leaves or drenching to soil. Chemical control of pests and diseases was undertaken when necessary.

2.5. Field experiment

The characteristics of the soil at the field experiment site were the same as those described for the soil used in the pot experiment, as the soil for the latter was taken from the same area as the site for the field experiment. Field preparation involved three plowings. A basal application of lime was made at a rate of 625 kg/ha. For high rate fertilizer treatment, N-P-K fertilizers (15-15-15) at rates of 28.13 kg/ha, 12.34 kg P/ha and 23.38 kg K/ha, respectively, were applied prior to planting, whereas in low rate fertilizer treatment, N-P-K fertilizers were applied at half the rate of the high rate treatment.

Individual plot size was 1 m × 5 m, with transplanted seedlings being spaced at 50 cm × 50 cm. Irrigation was provided manually, by applying water to the hills of tomato plants until 7 days after transplanting (DAT), with furrow irrigation then being used. Weeds were controlled manually during the growing season. Nitrogen and calcium fertilizer (15-0-0) as calcium nitrate ($Ca(NO_3)_2$) at rates of 1.5 kg N/ha and 2.25 kg Ca/ha, were applied at 14 days after transplanting (DAT). Commercial N-P-K fertilizers (15-15-15) at rates of 28.13 kg N/ha, 12.34 kg P/ha and 23.38 kg K/ha were applied at 21 DAT and N-P-K fertilizers (13-13-21) at rates of 24.38 kg N/ha, 10.75 kg P/ha and 32.69 kg K/ha at 40 DAT. For low rate chemical fertilizer treatment, N-P-K and calcium nitrate fertilizers were applied at half those rates.

Wood vinegar and FB were diluted with water in the ratios of 1:800 (v/v) and 1:500 (v/v), respectively. They were then applied to the plants as a foliar spray and soil drench around the plants. For the foliar spray application, the amounts of WV and FB required to wet all the leaves of the plants, varied with plant age, starting at 9.4 ml/plant from the time of planting, to 12.5, 14.1 and 15.6 ml/plant at subsequent 10 days intervals, until the time of harvest. For the soil drench, FB and WV were applied in consistent amounts of 22.5 l/plot per application. When the WV treatment was combined with the FB treatment, the spray and drench applications were made separately. Chemical control of pests and diseases was undertaken when necessary.

2.6. Data collection

Plant height was measured from the ground surface to the top of the plants at 30, 40, 50 and 90 DAT. Days-to-flowering was recorded in both experiments on days when 50% of total flowers were blooming. Inflorescence number and branch number were recorded at final harvest.

At 30, 60 and 90 DAT, SPAD chlorophyll meter readings (SCMR) at 0900–1200 h were recorded, using a Minolta SPAD-502 meter (Tokyo, Japan) on two plants in each pot and five plants in each plot of the field experiment. Measurements were made on the second fully expanded leaves from the tops of the main stem. Leaf area was measured once at 90 DAT, using an automatic area meter ACC-400 (Hayashi Denken).

Total above-ground dry weight accumulation (TDW) was measured at 30, 40, 60 and 90 DAT, using one plant and two plants for each replicate in the pot experiment and field experiment, respectively. The plants were cut at the level of the soil surface, with the stems, leaves and fruits being separated and subsequently oven-dried at 80 °C for 48 h. At final harvest, 90 DAT, fresh weight of ripe fruits was measured from one plant per replicate in the pot experiment and green fruits were classified as above ground dry weight, whereas all fully ripe tomatoes from eight plants in each plot were harvested in the field experiment. Total soluble solids (TSS) was determined using all ripe fruits from the plant for pot experiment, and 25 fruit from the field experiment, using a hand refractometer digital model PAL1 (ATAGO, Japan).

2.7. Statistical analysis

Analysis of variance was performed on data for each character. Duncan's multiple range test (DMRT) was used to compare means (Gomez and Gomez, 1984). The analyses of variance at this stage were done using MSTAT-C package (Bricker, 1989).

3. Results

3.1. Pot experiment

The application of fertilizer in the high fertilizer rate treatment significantly increased TDW, SCMR, leaf area and branch number at harvest but did not affect plant height, inflorescence number and flower number per inflorescence (data not shown). Using WV and FB, either as a foliar spray or soil drench, did not have any statistically significant effect on plant height, TDW, SCMR, leaf area, branch number and inflorescence number (data not shown)

The high rate of fertilizer gave a significantly higher fruit number ($P < 0.01$), fruit dry weight ($P < 0.01$) and TSS ($P < 0.01$); however, there was no effect on fruit fresh weight (Table 2). The application of WV and FB did not significantly increase fruit number, fruit fresh weight or fruit dry weight, but did significantly enhance TSS (Table 2). There was no significant effect of WV or FB. However when WV and FB were used in combination, there was an additive effect. Interactions between treatment agents and fertilizer rate were recorded (Table 2). The foliar spray applications of WV in combination with FB, significantly increased total soluble solids ($P < 0.01$) when fertilizer was applied at a low rate (Table 3).

3.2. Field experiment

The low fertilizer application rate did not affect plant height, branch number or inflorescence number at any growth stage, and also did not affect days-to-50% flowering (data not shown). There was no evident effect of the application of WV and FB, alone or in combination, on branch number, leaf area, inflorescence number and days-to-50% flowering (data not shown).

Tomato possessed the same TDW in both fertilizer rate treatments at 30, 40 and 60 DAT (Table 4). However, there was a significant increase in TDW ($P < 0.01$) in response to the higher fertilizer application rate at 90 DAT.

The application of WV and FB significantly increased TDW at 40, 60 and 90 DAT ($P < 0.01$), when compared with the untreated control. At 40 DAT, foliar spray application of WV gave the highest TDW (0.124 kg/m^2) followed by drenching with WV (0.122 kg/m^2) and foliar spray with FB (0.114 kg/m^2), respectively. At 60 and 90 DAT, soil drench with FB resulted in the highest tomato TDW (0.346 and 0.526 kg/m^2, respectively). However, foliar spray and soil drench with WV or FB alone or WV in combination with FB, were not significantly different from the control treatment of soil drenched with water. The effects of WV and FB on TDW were not significantly different, while the foliar spray and soil drench had similar effects (Table 4).

The high rate of fertilizer significantly promoted SCMR at 60 and 90 DAT, but the foliar spray or soil drench of FB or WV alone, and

Table 2
Effect of chemical fertilizer application rate, wood vinegar (WV) and fermented bio-extracts (FB), on fruit number, fruit fresh weight, fruit dry weight and total soluble solid (TSS) of tomato cv. *Delta*, grown in pot experiment in the 2008/2009 dry season.

Treatments	No. of fruit (fruit/plant)	Fruit fresh weight (g/plant)	Fruit dry weight (g/plant)	TSS (%)
Chemical fertilizer (a)				
High rate	10.6[a]	160.8	6.2[a]	6.8[a]
Low rate	7.2[b]	140.2	4.6[b]	5.6[b]
F-test (a)	**	NS	**	**
C.V. (%)	24.8	23.7	24.3	7.2
Treatment agents (b)				
Untreated control	8.6	137.2	3.8	5.9[bc]
Soil drench with water	8.3	148.8 (8.5)[1]	5.6	6.1[b]
Foliar with water	8.5	145.3 (5.9)	5.4	5.6[c]
Soil drench with FB	9.6	162.5 (18.4)	6.9	6.9[a]
Foliar with FB	9.1	169.1 (23.3)	7.1	6.2[b]
Soil drench with WV	8.6	148.7 (8.4)	5.7	6.1[b]
Foliar with WV	9.8	151.1 (10.1)	5.4	6.2[b]
Soil drench with FB + WV	8.6	151.1 (10.1)	6.5	6.8[a]
Foliar with FB + WV	8.6	154.3 (12.5)	5.3	6.3[b]
F-test (b)	NS	NS	NS	**
a × b	NS	NS	NS	**
C.V. (%)	15.8	16.2	18.5	7.0

Means in the same column with the same letters are not significantly different at $P < 0.05$ by DMRT.
NS, non significant.
[1] The numbers in parenthesis are percentage increased in fruit yield compared to untreated control.
** Significant at $P < 0.01$.

WV in combination with FB, did not show any significant effects on SCMR at 30, 60 and 90 DAT (Table 4).

Fruit number and TSS were not affected at the lower fertilizer application rate, but fruit fresh weight and fruit dry weight were significantly lower in the lower fertilizer treatment ($P < 0.01$) (Table 5). The reduction in fresh fruit yield was from 2.650 kg/m^2 to 1.821 kg/m^2, while the reduction in dry fruit yield was from 0.193 kg/m^2 to 0.133 kg/m^2 (Table 5).

Foliar spray and soil drench with WV and FB, alone or in combination, significantly increased fruit fresh weight ($P < 0.05$), fruit dry weight ($P < 0.05$) and total soluble solids ($P < 0.01$), but had no effect on fruit number, when compared with the untreated control. The effect of WV and FB application on tomato quality was clearly evident, with TSS being highest in tomato drenched with WV (5.7%), followed by foliar spraying with FB (5.6%) and foliar spraying with WV (5.5%), respectively. Wood vinegar had a higher efficacy than FB in enhancing TSS in tomato.

Table 3
Interaction effects between chemical fertilizer application rate and treatment agents on total soluble solid (TSS) of tomato cv. *Delta*, grown in pot experiment in 2008/2009 dry season.

Treatment agents	Total soluble solid (%)	
	High rate fertilizer	Low rate fertilizer
Untreated control	6.2[cd]	5.2[c]
Soil drench with water	7.0[ab]	5.6[b]
Foliar with water	6.8[bcd]	5.5[bc]
Soil drench with FB	7.1[ab]	5.5[bc]
Foliar with FB	6.0[d]	5.2[c]
Soil drench with WV	6.6[bcd]	5.5[bc]
Foliar with WV	7.1[ab]	5.3[bc]
Soil drench with FB + WV	6.5[bcd]	5.4[bc]
Foliar with FB + WV	7.8[a]	6.1[a]
F-test	**	**
C.V. (%)	15.8	7.0

Means in the same column with the same letters are not significantly different at $P < 0.05$ by DMRT.
** Significant at $P < 0.01$.

4. Discussion

The results from the two experiments revealed a clear response to the higher fertilization application rate in terms of TDW, SCMR, fruit number, fruit dry weight and TSS of tomato fruit. Lower yield in the pot experiment was evident possibly due to growth limitation by soil volume in the container with 27 cm in diameter and 20 cm in soil height. On the other hand, there was no limitation in root growth with plant spacing of 50 cm × 50 cm in the field experiment.

The findings of this study conform with the results of many other studies, in which higher yields of a range of vegetables were associated with high application rates of inorganic fertilizers (Stewart et al., 2005) and maximum value of growth (Badr and Fekry, 1998; Dauda et al., 2008). Specifically in relation to tomato, Direkvandi et al. (2008) found that high fruit number, high fruit weight and maximum yield were obtained in response to high application rates of inorganic fertilizer.

The application of WV and FB alone or in combination, were able to partially substitute for the use of chemical fertilizer, especially during the early growth stages. However, other factors might have contributed to this response, as the effect was only obtained in the field experiment. The beneficial effect of higher fertilizer application rate was found at 90 DAT. This could reflect the increased demand for plant nutrients when the tomato plants start setting fruit, when the foliar application of some macro- and micronutrients can efficiently alleviate potential nutrient deficiencies, as found in studies by Roosta and Hamidpour (2011) for tomato grown on aquaponics.

Smoke derived from the burning of plant materials has been extensively reported for its effectiveness in promoting the germination of plant species from both fire-prone and non-fire-prone environments, as well as agricultural and horticultural species (Dixon et al., 2009); it has also been reported to improve the growth and yield of several crop plants, including tomato (Kulkarni et al., 2007, 2008). The results from the pot and field experiments reported here, show that smoke in form of WV or pyroligneous acid, significantly increased growth and yield of tomato cv. *Delta*, when compared to the untreated control. However, when compared with the water drench control treatment, growth and yield

Table 4
Effect of chemical fertilizer application rate, wood vinegar (WV) and fermented bio-extracts (FB) on total above ground dry weight (shoot + leaf + fruit) and SPAD chlorophyll meter reading (SCMR) at 30, 40, 60 and 90 DAT of tomato cv. *Delta* grown in field experiment in the 2008/2009 dry season.

Treatments	Total above ground dry weight (kg/m^2)				SCMR		
	30 DAT	40 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Chemical fertilizer (a)							
High rate	0.069	0.113	0.314	0.501^{a}	55.2	49.2^{a}	39.0^{a}
Low rate	0.068	0.089	0.282	0.414^{b}	47.1	39.4^{b}	29.2^{b}
F-test (a)	NS	NS	NS	**	NS	*	*
C.V. (%)	23.4	22.8	26.4	26.7	22.8	23.6	30.7
Treatment agents (b)							
Untreated control	0.065	0.068^{c}	0.257^{c}	0.388^{c}	50.4	44.3	34.0
Soil drench with water	0.064	0.097^{b}	0.313^{ab}	0.465^{ab}	50.7	44.3	34.1
Foliar with water	0.063	0.099^{ab}	0.302^{b}	0.438^{bc}	48.5	44.2	33.9
Soil drench with FB	0.085	0.104^{ab}	0.346^{a}	0.526^{a}	54.7	44.7	34.5
Foliar with FB	0.076	0.114^{ab}	0.299^{bc}	0.482^{ab}	53.1	45.1	34.9
Soil drench with WV	0.067	0.122^{ab}	0.296^{bc}	0.464^{ab}	51.9	42.7	32.4
Foliar with WV	0.078	0.124^{a}	0.316^{ab}	0.493^{ab}	48.0	43.6	33.4
Soil drench with FB + WV	0.067	0.110^{ab}	0.289^{bc}	0.455^{b}	51.1	45.5	35.3
Foliar with FB + WV	0.072	0.105^{ab}	0.304^{b}	0.480^{ab}	52.7	44.6	34.3
F-test (b)	NS	**	**	**	NS	NS	NS
a × b	NS	NS	NS	NS	NS	NS	NS
C.V. (%)	13.8	21.5	12.7	12.6	12.6	16.7	21.7

Means in the same column with the same letters are not significantly different at $P < 0.05$ by DMRT.
NS, non significant; DAT, days-after-transplanting
* Significant at $P < 0.05$.
** Significant at $P < 0.01$.

were slight enhanced, but not significantly different, in response to WV.

The responses of tomato to WV application in these experiments were less than achieved, compared to those reported by Kulkarni et al. (2008). This may reflect differences in the timing of application. In these experiments, tomato was first treated with WV, either as a foliar spray or soil drench, after transplanting (30 DAE). In the study reported by Kulkarni et al. (2008), smoke-water was used for irrigation, immediately after sowing. Younger seedlings may be more responsive to known compounds such as karrikinolide or karrikins-plant growth regulators, in smoke. This compound stimulates germination and enhances seedling development as found in maize (Van Staden et al., 2006) and tomato (Kulkarni et al., 2007). It may therefore have an effect on cell division and subsequently resulted in a significant increase in above ground biomass. The increased in biomass of tomato was related to increase branching, leaf number and plant height (Kulkarni et al., 2008).

Much attention has been paid to karrikinolide, as it has been identified in smoke. However, in WV, there are other significant components, including organic acids, with acetic acid being one of main components, and various forms of alcohol, that might affect plant growth. Ethanol has been reported to have a stimulatory effect on the germination of grass seed, including Bermuda grass (*Cynodon dactylon* L. Pers.) (Salehi et al., 2008), and indica and

Table 5
Effects of chemical fertilizer application rate, wood vinegar (WV) and fermented bio-extracts (FB) on fruit number, fruit fresh weight, fruit dry weight and total soluble solid (TSS) of tomato cv. *Delta* grown in field experiment in the 2008/2009 dry season.

Treatments	No. of fruit (per plant)	Fruit fresh weight (kg/m^2)	Fruit dry weight (kg/m^2)	Total soluble solid (%)
Chemical fertilizer (a)				
High rate	14.7	2.650^{a}	0.193^{a}	5.2
Low rate	13.4	1.821^{b}	0.133^{b}	5.4
F-test (a)	NS	**	**	NS
C.V. (%)	28.7	22.5	22.6	19.8
Treatment agents (b)				
Untreated control	12.2	1.805^{b}	0.132^{b}	4.7^{d}
Soil drench with water	14.5	2.074^{ab} (14.9)[1]	0.151^{ab}	5.2^{bcd}
Foliar with water	12.6	1.860^{b} (3.0)	0.136^{b}	5.1^{cd}
Soil drench with FB	14.6	2.461^{a} (36.3)	0.179^{a}	5.2^{bcd}
Foliar with FB	15.8	2.510^{a} (39.1)	0.183^{a}	5.6^{ab}
Soil drench with WV	15.1	2.294^{ab}(27.1)	0.167^{ab}	5.7^{a}
Foliar with WV	15.2	2.428^{a} (34.5)	0.177^{a}	5.5^{abc}
Soil drench with FB + WV	13.3	2.264^{ab}(25.4)	0.165^{ab}	5.1^{cd}
Foliar with FB + WV	14.0	2.418^{a} (34.0)	0.176^{a}	5.1^{cd}
F-test (b)	NS	*	*	**
a × b	NS	NS	NS	NS
C.V. (%)	20.0	22.1	22.3	8.5

Means in the same column with the same letters are not significantly different at $P < 0.05$ by DMRT.
NS, non significant.
[1] The numbers in parenthesis are percent increase in fruit yield compared to the untreated control.
* Significant at $P < 0.05$.
** Significant at $P < 0.01$.

japonica rice under aerobic conditions (Miyoshi and Sato, 1997); the latter authors proposed that ethanol stimulates germination under aerobic conditions through an involvement of activation of Kreb's cycle and/or glycolysis. Wood vinegar contains only small amounts of N, P and K (Table 1), it may therefore not have the same effects as foliar fertilizer. This conclusion is supported by measurements of chlorophyll content in the leaf measured using a SPAD chlorophyll meter reading (SCMR), which showed there was no change in chlorophyll leaf content in response to the application of WV at any growth stage. Wood vinegar has been reported for its synergistic effects on the insecticidal activity of carbosulfan. This might be related to activity facilitation effects of the WV (Kim et al., 2010). Therefore, foliar spray or soil drench forms of WV, may enhance nutrient uptake ability by plants. This could be further examined through a study of the effects of WV on nutrient accumulation in plants. The enhancing effects on growth and yield of tomato might be also due to the repellent properties of WV, but further studies on this possibility are needed.

The results of the experiments indicated that FB or bio-extract, enhanced growth and yield of tomato in a similar way to WV. Additional effects were evident when WV and FB were applied together. Fermented bioextracts has been reported to promote growth and yield of tomato (Suwanburt et al., 1996) and Chinese kale (Noisopa et al., 2010). Nopamornbodi et al. (2004) reported that bio-extracts provide both nutrients and micro-organisms beneficial to plants. This was in contrast to Kamla et al. (2008) who reported that bio-extracts did not provide a significant source of nutrients for a crop, but, when used in combination with organic fertilizer, it increased the activity of soil micro-organisms and thus promoted crop growth and yield. Plant growth regulators such as indole acetic acid (IAA), gibberellic acid (GA_3) and zeatin, were found in significant amounts in both animal-based and plant-based extracts. Previous work has suggested that the microorganisms in fermented products may play an important role in increasing crop yields (Higa, 1994; Hussain et al., 1999; Khaliq et al., 2006).

Foliar spray and soil drench provided the same responses in tomato in these experiments. The use of a soil drench may be less time consuming but may use more WV and FB than the use of foliar sprays. Further study and clarification is needed on the possible effects of application method, on the activity of soil micro-organisms.

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