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

Tuntika Mungkunkamchao[a,1], Thawan Kesmala[a], Sumran Pimratch[b], Banyong Toomsan[a], Darunee Jothityangkoon[a,*]

[a] Department of Plant Science and Agricultural Resources, Faculty of Agriculture, Khon Kaen University, Khon Kaen 40002, Thailand
[b] Department of Agriculture, Faculty of Agricultural Technology, Rajabhat Maha Sarakham University, Maha Sarakham 44000, Thailand

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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).

* Corresponding author. Tel.: +66 43 342 949; fax: +66 43 364 636.
E-mail addresses: darcho@kku.ac.th, djothit@gmail.com (D. Jothityangkoon).
[1] Current address: Nong Khai Land Development Station, Nong Khai 43000, Thailand.

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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-1-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.