



RECENT HEADWAYS IN POMOLOGY

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CHAPTER 5

A RESEARCH ON THE USE OF WOOD VINEGAR (PYROLYSIS ACID) AND BIOCHAR IN THE HORTICULTURAL PRODUCTION

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INTRODUCTION

Due to the rapid population growth, agricultural lands have been used extensively to meet the nutritional and shelter needs of the people recently, resulting in soil exhaustion and soil pollution. The technological developments affect the agricultural sectors in the world as well. For this reason, developed countries has started to perform natural and different applications in order to ensure the sustainability of agricultural production areas, to reduce soil pollution, to restore the flora and fauna of agricultural soils, and to improve soil chemistry. One of these applications is the use of wood vinegar. However, in Turkey as the agriculture is not considered as an industry, synthetic production inputs are uncontrolledly used and also a very intensive agricultural production is carried out without considering the consequences of negative processing techniques and technologies, just like in the developed countries of the world (Tarhan, 2005).

Wood vinegar is a by product from the charcoal production process (Fengel and Wegener, 1984). It contains more than 200 chemicals including wood vinegar, acetic acid, methanol, phenol, ester, acetal, ketone, formic acid and many other organic chemicals (Mu et al., 2003; Kadota and Nimii, 2004). Wood vinegar consists mainly of water soluble compounds, over 200 kinds. Its main ingredients are organic. Acetic acid acids, phenolics, alkanes, alcohol and ester compounds are its main components. There are many uses for wood vinegar in the agriculture (Jothityangkoon et al., 2007). Wood vinegar when used as foliar fertilizer enhances yields in cucumber, lettuce and cole (Mu et al.,

2006; Jothityangkoon et al., 2007). Mixing charcoal and wood vinegar in planting materials improves growth, branching and survival rate of *Zinnia* and increases yield of it (Kadota and Niimi, 2004). In recent years, wood vinegar has been used in horticultural agriculture as plant growth regulator to improve soil quality, prevent soil-borne diseases and pests, support root growth and enhances the growth of stems, leaves, and flower and fruits (Mu et al., 2003, 2004; Burnett, 2013). Especially in organic farming, producers use wood vinegar, which is an organic product rather than toxic chemicals in plant growing against diseases and pests. In addition, wood vinegar promotes seed germination, plant growth, improves fruit quality, and acts as a herbicide in weed control (Loo et al., 2007). It has been determined that wood vinegar in horticulture reduces the harmful effects of pathogenic factors such as *Fusarium* spp., *Phytium* spp. ve *Rhizoctonia* spp. that adversely affect fruit trees. It has been reported that when used at the appropriate concentration, it promotes the fertilizer consumption and reduces the damage of many diseases. It is also known that wood vinegar helps plants to meet their nutritional needs for growth by absorbing soil nutrients, improve hairy root growth and stimulate the soil microbial community (Namlı et al., 2014). In the experiment conducted to determine the effects of bamboo vinegar on lettuce, cucumber and rape seeds, Mu et al. (2003) stated that using wood vinegar diluted 500 times increases yield between 18.8-20.2%, and has an effect on plant height and weight compared to control (Jun et al., 2006) When wood vinegar is applied on plant leaves, the leaves become shiny and darker in color. This is due to the increase in chlorophyll

through the effect of ester in the wood vinegar which promotes photosynthesis. This ester also helps in the formation of sugar and amino acids. This also results in a better taste of the produce. The healthier leaves naturally have a stronger resistance against pests and diseases. (Velmurugan et al., 2009). The fruit quality is closely related to health of the plant. Therefore, wood vinegar significantly improves the fruit quality and quantity. Besides, wood vinegar increases the value of the products, because excessive pesticides are not used, in both domestic and foreign markets. Since synthetic drugs used as biocides have harmful effects on human health, the advantage of the bactericidal and fungicidal properties of wood vinegar should be taken in order to reduce the negative effect. The effects of wood vinegar, which is presented to the producers as a alternative to chemical fertilizers and pesticides in the market, should be clearly explained to producers, and studies on the use of wood viegar should be regard as necessary in order to contribute to the sustainable use of soils (Namlı et al., 2014).



Figure 1: Wood vinegar application in strawberry garden (Silifke / Mersin)

Reference: Niyazi Cin/ Çelebi Company.

The Thai Ministry of Agriculture reported that wood vinegar was used towards soil quality improvement, pest elimination, plant growth stimulation, promotion of the growth of roots, stems, tubers, leaves, flowers and improvement of yield. At the same time, it enhance the root growth by increasing the beneficial microbial population.

The aim of this study is to improve the deteriorated soil structure due to excessive fertilization, pesticide and irrigation, to restore the degraded ecosystem by enabling plants to absorb nutrients more easily, and to examine the effects of wood vinegar and biochar application on horticultural agriculture as an alternative to chemical fertilizers and pesticides in order to ensure the sustainability of agricultural areas.

1.APPLICATION OF WOOD VINEGAR FOR PEST AND DISEASE MANAGEMENT

In recent years, in order to reduce the use of pesticides with the purpose of protecting food safety and natural balance, there has been a global shift towards more environmentally sustainable ways of managing pests and plant diseases. Pesticides are produced in a way that neutralizes specific target organisms or groups of organisms that harm economic agricultural products. However, pesticides disrupt the natural balance. The effects of long lasting pesticides (usually chlorinated hydrocarbons) and permanent pesticides (consisting of arsenic, lead or mercury) are quite dangerous to natural balance except for those that are moderately lasting due to their natural, organic and synthetic properties (Karaismailoğlu, 2016; El- Nahas et al., 2017; Kayhan, 2020). Scientific researches proceed intensively in order to discontinue

the pesticide use and to increase the preference of environmentally friendly applications. For this purpose, in a study conducted by Ahadiyat et al, they reported that they greatly reduced the harmful effects of fungal disease of coconut shell by applying the concentration of wood vinegar of ratio 1:20, 1:20, 1:40, 1:60, 1:80, 1: 100 to coconut shell. Wood vinegar, extracts of Mexican turnip and the seed of Chinaberry tree are used within the study carried out against housefly. They reported that because wood vinegar causes disorders in the larval, pupal and adult stages, it prolongs the duration of their development period and shorten the life span of adults (Pangnakorn et al., 2012). Chalermisan et al. (2009) reported in a study they conducted that wood vinegar (pyrolysis acid) could be an effective fungicide that can be used against fungal diseases which damage plants. Moreover, the reason why wood vinegar has antifungal properties is due to the phenolic compounds it contains (Baimark & Niamsa, 2009).



Figure 2: Images after wood vinegar application in Nova Tangerine garden
(Şahinağa Village/ Adana)

Reference: Niyazi Cin/ Çelebi Company.

Wood vinegar is effective against pathogenic fungi such as *Alternaria mali*, *Rhizoctonia solani*, *Sclerotium oryzae*, *Helminthosporium maydis*, *Pythium sp.*, *Colletotrichum gloeosporioides* and *Choanephora cucurbitarum* in horticultural crops (Chalermnan et al., 2009; Jung, 2007). It has been detected using different application rates of wood vinegar that the growth of *Coriulus versicolorum* and *Gloeophyllum trabeum* is inhibited in order to identify the antifungal properties (Chen et al., 2012). Besides, wood vinegar is widely used in animal products against external parasites and insects such as flies, ticks, fleas. (Chan et al., 2012; Rakmai, 2009). It has been recorded that wood vinegar is an effective repellent for the control of the vole (*Clethrionomys glareolus bedfordiae*), slugs (*Arion lusitanicus*) and snails (*Aranta arbustorum*) damaging the plants. (Lindqvist et al., 2010). In another study, it was reported that wood vinegar has positive effect on the growth of wheat plants and contributed to the improvement of soil properties. The effect of various forms of wood vinegar on wheat development and a series of soil chemical characteristics was investigated in a greenhouse experiment by Namlı et al. (2014). In the same study, it has been determined that the application rate of 0.5 %, wood vinegar can completely inhibited *C. ceticola* development at a rate of 77,4-91,1 %. In line with the data obtained in the study it is concluded that wood vinegar can be alternatively used as a biocide agent *in vivo* conditions. In a study conducted by Saberi et al. (2013), different concentrations of wood vinegar (0.125%, 0.25% and 0.50%) reduced the pathogenicity rate of the pathogens of *Rhizoctonia solani* and *Sclerotinia sclerotiorum* in cucumber (*Cucumis sativus* L.) up to

87% compared with the control. In a study conducted in Indonesia, it was reported that wood vinegar provided a natural protection against anthracnose (*Colletotrichum* sp.) on pepper (*Capsicum annuum* L.) According to this research, different concentrations of wood vinegar (0.40; 0.42; 0.44; 0.46; 0.48; 0.50; and 0.52%) are used and it is reported that the rates of 0.50 and 0.52% have the best results. Therefore, they stated that it reduced anthracnose in hot peppers up to 87.98% (Wardoyo et al., 2020).

2.THE EFFECTS OF WOOD VINEGAR AND BIOCHAR ON YIELD AND QUALITY OF PLANTS

Fertilization is carried out with the intent to protect and improve soil productivity in order to ensure the sustainability of vegetative production and high yield from plants (Bellitürk, 2011). Productivity in agriculture depends on making up for mineral deficiencies in the soil and meeting the nutrient demand of products. Producers have recently started to use chemical fertilizers intensively to obtain more products



Figure 3: Application of biochar (Erdemli/Mersin)

Reference: Niyazi Cin/ Çelebi Company.

per unit area in order to meet the nutritional needs of the increasing world population. However, it has become a fact accepted by all scientific circles that chemical fertilizers contaminate the soil and groundwater resources. This situation endangers the sustainability concept in agricultural production. While chemical fertilizers, which have been used for years, have increased productivity in agriculture, they cause the exhaustion of the soil, sodification, desertification and degradation of soil. As a result of this, researchers today recommend the use of alternative nature-friendly fertilizers such as biofertilizer, vermicompost and biochar, which have the capacity to successfully reverse the negative effects of chemical fertilizers (Yetkin, 2010; Aydın, 2019).

In a study conducted by Zulkarami et al., (2011) in Malaysia, three fertilizer formulations namely; (M), Cooper Standard (CS) and Benoit(BEN), a local formulation commonly used by farmers containing calcium nitrate, potassium nitrate, magnesium sulfate and mono potassium were evaluated in combination with four levels of pyroligneous acid (0,10, 20 and 30%) for enhancement of growth, fruit yield and quality of rockmelon in soilless culture. The concentration of 30% was toxic as most plants died while the concentration of 20% increased the growth and yield of rockmelon plants. However, it is reported that the local M fertilizer in combination with 10% pyroligneous acid gave the best results. In different studies, it is reported that the combination of wood vinegar and charcoal increased soil fertility for rice (*Oryza sativa*), melon (*Cucumis melo*), sweet potato (*Ipomoea batatas*), sugar cane (*Saccharum officinarum*), tomato

(*Lycopersicum esculentum*) (Kadota et al., 2002; Tsuzuki et al., 1989; Du et al., 1997; Du et al., 1998; Uddin et al., 1995; Mungkunkamchaoa et al., 2013). Moreover, it is stated that it significantly increased plant growth in vegetable species such as lettuce (*Lactuca sativa*), canola (*Brassica napus*) and cucumber (*Cucumis sativa*) (Mu et al., 2003). Due to utility of wood vinegar as soil conditioner, it increases enzyme activity in the soil and reduces the toxic effect of heavy metals in the soil by minimizing ammonia volatilization (Lashari et al., 2013; Win et al., 2009; Liu et al., 2018). In a study conducted to analyze the effect of wood vinegar on seed germination and seedling growth, the seeds of corn are dipped in wood vinegar of different densities. Later, corn seeds were monitored in the germination media and it has been observed that concentrations of wood vinegar had obvious effects on up-ground length and up-ground dry weight of corn seedlings but there was no significant difference on chlorophyll value and dry weight underground (Zhou et al., 2009).

Biochar, which is a product synthesized through pyrolysis acid and carbonized carbon of different biomasses of plant or animal waste, is a material that has the property of improving the soil and the environment. Biochar also affects the soil microbial activity, facilitates the uptake of nutrients and water, thus increases yield (Ahmad et al., 2014; Zheng et al., 2013; Zheng et al., 2013; Jones et al., 2012; Razaq et al., 2017). In a comparative study on blueberry, it is observed that when wood vinegar was applied alone or combined with biochar in the nutrient medium of the blueberry, the amount of $\text{NH}_4^+ - \text{N}$, $\text{NO}_3^- - \text{N}$, and Mg in the soil, plant growth, and the fruit yield was increased. In

addition, it is found that vitamin C content and mineral substances increased but the titratable acidity decreased within the blueberries.

In conclusion, it has been stated that when wood vinegar is applied alone or combined with biochar, it improves soil structure and increases nutrient contents (Zhang et al., 2020). A study was carried out on the three seedlings of mango in randomized complete block design with two (2) treatments, three (3) sub-treatments, and three (3) replications with five (5) samples per replication. According to this study, control and 20 ml wood vinegar were applied and while there was no significant variation observed in the plants under control, significant differences were observed in the height of the mango seedling applied wood vinegar. It has been reported that wood vinegar applications accelerate root and leaf growth in mango seedlings (De et al., 2021).

3.THE USE OF WOOD VINEGAR FOR PRESERVING HORTICULTURAL PLANTS

In a study conducted in China in order to keep-fresh effect of harvested Jingya grapes by increasing the shelf life, harvested Jingya grapes were immersed in three different concentration of wood vinegar (5.0 g/L, 3.4 g/L and 2.5 g/L) and 100.0 g/L garlic juice, 6.7 mol/L of ethanol, mixtured solutions of 3.4 g/L wood vinegar and 100.0 g/L garlic juice for 2 minutes, then stored under room temperature (20 –25 °C). The best result is obtained from 5.0 g/L wood vinegar. As a result, it has been reported that application of 5.0 g/L wood vinegar to Jingya grapes after harvest reduces the respiratory rate, water loss, rotting rate and content of malondialdehyd (MDA) of grapes, delayed the aging of

grapes and extend the freshness and shelf life of grapes (Xue et al., 2009). In a study conducted in China in 2013 in order to determine the effect of wood vinegar against *R. nigrificans* (black rot) factor formed on peach after preservation; the inhibition effect of wood vinegar concentrations of 10, 20, 25, 33.4, 50 and 100.0 g/L, and 100.0 g/L were investigated. In this study, peaches were immersed in wood vinegar concentrations of 12.5, 16.7, 25.0 and 50.0 g/L for 2 minutes and then stored at 20-23 °C. It is observed that the spore germination of *R.nigrificans* is significantly reduced. It has been reported that fruits preserve their freshness and significantly extend their shelf life. In particular, it has been reported that the application of 5.0 g/L wood vinegar reduces the rotting rate and water loss, the respiratory rate and the content of malondialdehyde (MDA) in fruits, delayed the aging and extend the freshness and shelf life (Xue et al., 2013). In China, Shi et al. (2019) also investigated effects of bamboo vinegar and peach gum on grey mould (*Botrytis cinerea*) in blueberry. According to this study, blueberries were immersed in different concentration of wood vinegar (BV: 0.1, 0.5, 1 and 1.5% v/v) and peach gum (PG: 0.5, 1, 2 and 3% w/v) solutions under room temperature for two minutes. In this study, it is reported that wood vinegar combined with peach gum preserved the quality of product and delayed aging by controlling gray mold disease development during storage and activating antioxidant enzymes such as CHI (chitinase), GLU (glucanase), PAL (phenylalanine ammonia-lyase), PPO (polyphenol oxidase) and POD (peroxidase) that have an important role in preserving fruit quality. Jun and Zhang (2010) used solutions consisting of wood vinegar + chitosan and chitosan + acetic

acid mixtures to extend the shelf life of cherry-tomatoes in their study. According to the results of this study, they reported that when wood vinegar + chitosan was applied, the weight loss ratio is reduced, the appearance and quality are increased, and the shelf life is extended.

CONCLUSION

As the world population increases, the food demand increases correspondingly. Therefore, in terms of agricultural production, it has become necessary to obtain more products per unit area in agricultural lands and to use it more intensively. At the same time, using more fertilizer, more pesticides against disease and pests, and more water has been a must due to the necessity of intensive use of agricultural lands and the need to obtain high yield per unit area and this lead to the sodification and salinization of soils, degradation of soil fauna and flora, soil pollution and desertification. For this reason, agricultural researchers are in search of new environmentally friendly agricultural production methods (such as good agricultural practices, organic agriculture, ecological agriculture, biological agriculture) to restore the deteriorated agricultural soil and ecosystem. Especially, they aimed to improve the soil structure with practices such as good agriculture and organic agriculture. For this purpose, instead of using pesticides against diseases and pests, biomass including organic environmentally-friendly ingredients, organic fertilizers of vegetables and animals, as well as applications of soil regulators as biochar and wood vinegar have become recently popular in developed and developing countries, especially in East Asian countries. The aim is to increase the use of

environmentally-friendly biochar and wood vinegar in order to recover the soil deterioration due to excessive use of pesticides, chemical fertilizers and unconscious use of water since agricultural production has been carried out with traditional methods for many years. Applications of wood vinegar and biochar both improve the soil structure and facilitate the intake of nutrients and water, allowing plants to grow faster and give higher yields. Especially in the production of horticultural plants, soilless culture and fruit production, as application of wood vinegar and biochar promotes the potassium uptake in order to the plants have a strong root system, it helps plants to grow healthier by preventing soil borne diseases and damages. There are still ongoing researches on whether wood vinegar can be used as an alternative to fungicides containing pesticides against soil borne fungal diseases such as *Fusarium spp*, *Sclerotinia sclerotiorum*, *Verticillium spp*, *Bortrytis cinerea*, *Penicillium italicum*, *C. beticola*, *R.nigrican*, *Alternariamali*, *Rhizoctonia solani*, *Sclerotium oryzae*, *Helminthosporium mayis*, *Pythium spp.*, *Colletotrichum gloeosporioides* ve *Choanephora cucurbitarum*, *Leveillula spp*, *Monilinia spp* that negatively affect yield and quality in plant cultivation. Besides, researches continues to verify that it has a repellent effect against pests such as root knot nematodes (*Meloidogyne spp.*), aphids (*Aphididae spp.*), fruit flies (*Ceratitis capitata*), fruit moths (*Cydia molesta* Busck), fruit worm (*Capnodis spp.*), vole (*Clethriono mysrufocanus bedfordiae*) slugs (*Arionlusitanicus*) and snails (*Arantaarbustorum*). For this reason, an environmentally-friendly practice is important in terms of food safety against both fungal diseases and pests that cause damage to plants.

When wood vinegar and biochar are used in appropriate concentrations, they provide healthier leaves and higher fruit yield and flowering especially regarding the fruit trees. At the same time, it has been reported by many researchers that wood vinegar is very effective in extending the shelf life of the products after harvest and it promotes seed germination, seedling and growth of the plants when used in different concentrations and combinations. For example, it is tested and verified that the shelf life of fruits such as grapes, peaches, blueberries and mangoes increased when they were immersed in a different wood vinegar solutions after harvest.

In conclusion it is necessary to carry out more detailed studies in order to increase the use of biochar and wood vinegar in agricultural production. There is a need for more comprehensive studies on its usability as a rooting medium, especially in tissue culture applications. Moreover, it is recommended that more detailed studies on using wood vinegar in terms of preserving fruits and vegetables should be performed. In addition, this study can be considered as important for shedding light on more comprehensive studies to be carried out in the future.

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Çelebi Company which inspired us to write this study is one of the few companies in Turkey that invest in the use of wood vinegar and biochar and carry out R&D studies accordingly. It is also the largest company that produces fabricated wood vinegar. Therefore, due to the studies and activities they have carried out, they have led us to write this article.

REFERENCES

- Ahmad, M., Rajapaksha, A.U., Lim, J.E., Zhang, M., Bolan, N., Mohan, D., Vithanage, M., Lee, S.S., Ok, Y.S. (2014) Biochar as a sorbent for contaminant management in soil and water: a review. *Chemosphere*. 99: 19–33.
- Aydın, İ. (2019). Gonen example of biofertilizer production activities which are indispensable for environmentally friendly agricultural applications. *The Journal of Kesit Academy*. (20): 11-25.
- Baimark, Y. & Niamsa, N. (2009). Study on wood vinegars for use as coagulating and antifungal agents on the production of natural rubber sheets. *Biomass and Bioenergy*. 33(6-7): 994-998.
- Burnette, R. (2013). An introduction to wood vinegar. ECHO Asia Regional Office, Durrance Road, North Fort Myers, USA. Retrieved from: <http://c.ymcdn.com/sites/www.echocommunity.org>.
- Chalermisan, Y. and Peerapan, S. (2009). *As. J. Food Ag-Ind. Special Issue*: 189-195.
- Chan, E., Tan, Y.P., Chin, S.J. and Gan, L.Y. (2012). *ISME/GLOMIS Electronic Journal*, 10(7): 19-21.
- Chen, S., Feng, Y., Li, S. and Mu, J. (2012). In the 55th International Convention of Society of Wood Science and Technology. Beijing, China.
- De Guzman, R. S. and Adalla, J. A. (2021). Growth of First Three Seedlings From Poly-Embryonic Mango Seed Applied With Wood Vinegar.
- Du, H. G., Ogawa, M., Ando, S., Tsuzuki, E. and Murayama, S. (1997). Effect of mixture of charcoal with pyroligneous acid on sucrose content in netted melon (*Cucumis melo* L. var. *reticulatus* Naud.) fruit. *Japanese journal of crop science*. 66(3): 369-373.
- Du, H.G., M Mahendradatta, S.A. S. and Tsuzuki, E. (1998). *Japanese Journal of Crop Science*. 67: 149-152.
- El Nahas, E.F., Abdel-Razek, A.S., Helmy, N.M., Mahmoud, S., Ghazy, H.A. (2017). Impaired antioxidant gene expression by pesticide residues and its relation with other cellular biomarkers in Nile Tilapia (*Oreochromis niloticus*) from Lake Burullus. *Ecotoxicology and Environmental Safety*. 137: 202-209.

- Fengel, D., Wegener, G. (1984). *Wood: Chemistry, Ultrastructure, Reactions*. Walter de Gruyter, Berlin.
- Jones, D.L., Rousk, J., Edwards-Jones, G., DeLuca, T.H., Murphy, D.V. (2012). Biochar-mediated changes in soil quality and plant growth in a three year field trial. *Soil Biol. Biochem.* 45:113-124.
- Jothityangkoon, D., Ruamtakhu, C., Tipparak, S., Wanapat, S., Polthanee, A. (2007). Using wood vinegar in increasing rice productivity. pp. 28-34. In *Proceedings of the 2nd International Conference on Rice for the Future*. Queen Sirikit National Convention Center, Bangkok, Thailand.
- Jothityangkoon, D., Koolachart, R., Wanapat, S., Wongkaew, S. and Jogloy, S. (2008). Using wood vinegar in enhancing peanut yield and in controlling the contamination of aflatoxin producing fungus. *International Crop Science*. 4: 253-253.
- Jun, M. U. and Zhang, L. (2010). Research on the Fresh-keeping Effect of Chitosan/Bamboo Vinegar on Cherry-tomato [J]. *Packaging Engineering*, 17.
- Jung, K. H. (2007). Growth inhibition effect of pyroligneous acid on pathogenic fungus, *Alternaria mali*, the agent of alternaria blotch of apple. *Biotechnology and Bioprocess Engineering*. 12(3): 318-322.
- Kadota, M. and Niimi, Y. (2002). *Journal of Horticultural Science*. 101: 327-332.
- Kadota, M., Niimi, Y. (2004). Effects of charcoal with pyroligneous acid and barnyard manure on bedding plants. *Scientia Horticulturae*. 101:327-332.
- Karaismailoğlu, M.C. (2016). The evaluation of the genotoxic and cytotoxic effects of Pyriproxyfen insecticide on *Allium cepa* somatic chromosomes with mitotic activity, chromosome abnormality and micronucleus frequency. *Turkish Journal of Life Sciences*. 1(2): 65-69.
- Kayhan, F. E. (2020). The Cycle of Insecticides on Nature and Its Effects on the Aquatic Environment. *Selcuk University Journal of Science Faculty*. 46(2): 29-40.
- Lashari, M.S., Liu, Y., Li, L., Pan, W., Fu, J., Pan, G., Zheng, J., Zheng, J., Zhang, X., Yu, X. (2013). Effects of amendment of biochar-manure compost in conjunction with pyroligneous solution on soil quality and wheat yield of a

- salt-stressed cropland from Central China Great Plain. *Food Crop Res.* 144:113-118.
- Lindqvist, I., Lindqvist, B. and Tiilikkala, K. (2010). Birch tar oil is an effective mollusc repellent: field and laboratory experiments using *Arianta arbustorum* (Gastropoda: Helicidae) and *Arion lusitanicus* (Gastropoda: Arionidae). *Agricultural and Food Science.* 19(1): 1-12.
- Liu, L., Guo, X., Wang, S., Li, L., Zeng, Y., Liu, G. (2018). Effects of wood vinegar on properties and mechanism of heavy metal competitive adsorption on secondary fermentation based composts. *Ecotox Environ Safe.* 150: 270-279.
- Loo, A.Y., Jain, K., Darah, I. (2007). Antioxidant and radical scavenging activity of the pyroligneous acid from a mangrove plant, *Rhizophora apiculata*. *Food Chemistry.* 104: 300-307.
- Mu, J., Yu, Z. M., Wu, W. Q. and Wu, Q. L. (2006). Preliminary study of application effect of bamboo vinegar on vegetable growth. *Forestry Studies in China.* 8(3): 43-47.
- Mu, J., Uehara, T. and Furuno, T. (2003). Effect of bamboo vinegar on regulation of germination and radicle growth of seed plants. *Wood Science and Technology.* 49: 262-270.
- Mungkunkamchaoa, T., Kesmalaa, T., Pimratchb, S., Toomsana, B. and Jothityangkoon, D. (2013). *Scientia Horticulturae.* 154: 66-72.
- Namlı, A., Akça, M. O., Turgay, E. B. and Soba, M. R. (2014). Investigation of Potential Agricultural Use of Wood Vinegar. *Soil Water Journal.* 3(1): 44-52.
- Pangnakorn, U., Kanlaya, S. and Kuntha, C. (2012). *International Journal of Medical and Biological Sciences.* 6: 283-286.
- Rakmai, J. (2009). *Pharmaceutical Science [Thesis].* Prince of Songkla University: Thailand.
- Razaq, M., Shen, H., Sher, H.L., Sher, H., Zhang, P. (2017). Influence of biochar and nitrogen on fine root morphology, physiology, and chemistry of *Acer mono.* *Sci Rep.* 7(1): 5367.
- Saberi, M., Sarpeleh, A., Askary, H. and Rafiei, F. (2013). The effectiveness of wood vinegar in controlling *Rhizoctonia solani* and *Sclerotinia sclerotiorum* in green

- house-cucumber. International Journal of Agricultural Research and Natural Resources. 1: 38-43.
- Shi, Z., Deng, J., Wang, F., Liu, Y., Jiao, J., Wang, L. and Zhang, J. (2019). Individual and combined effects of bamboo vinegar and peach gum on postharvest grey mould caused by *Botrytis cinerea* in blueberry. Postharvest Biology and Technology. 155: 86-93.
- Turhan, Ş. (2005). Sustainability in Agriculture and Organic Farming. Turkish Journal of Agricultural Economics. 11(1-2): 13-24.
- Tsuzuki, E., Wakiyama, Y., Eto, H. and Handa, H. (1989). Effect of pyroligneous acid and mixture of charcoal with pyroligneous acid on the growth and yield of rice plant. Japanese Journal of Crop Science. 58(4): 592-597.
- Murayama, S., Ishimine, Y., Tsuzuki, E. and Harada, J. (1995). Studies on sugarcane cultivation: II. Effects of the mixture of charcoal with pyroligneous acid on dry matter production and root growth of summer planted sugarcane (*Saccharum officinarum* L.). Japanese journal of crop science. 64(4): 747-753.
- Velmurugan, N., Chun, S.S., Han, S.S., Lee, Y.S. (2009). Characterization of chikusakueki and mokusaku-eki and its inhibitory effect on sapstaining fungal growth in laboratory scale. International Journal of Environmental Science and Technology. 6(1): 13-22.
- Wardoyo, E. R. P., Anggraeni, W. and Oramahi, H. A. (2020). Aktivitas Antifungi Asap Cair Dari Tandan Kosong *Elaeis guineensis* Jacq. Terhadap *Colletotrichum* sp. (WA2). Jurnal Bioteknologi & Biosains Indonesia (JBBI). 7(2): 271-279.
- Win, K.T., Toyota, K., Motobayashi, T., Hosomi, M. (2009). Suppression of ammonia volatilization from a paddy soil fertilized with anaerobically digested cattle slurry by wood vinegar application and floodwater management. Soil Sci Plant Nutr. 55(1):190–202.
- Xue, G. X., Chen, Z. J. and Li, Y. H. (2009). Study on keeping-fresh effect of Jingya grape with wood vinegar. Food Science and Technology. 12.

- Xue, G. X., Huang, S. C. and Song, Y. D. (2013). Study of wood vinegar on inhibition and keeping-fresh effect of *R. nigrican* Ehrenbof peach and *Prurms persica* [J]. Journal of Agricultural Science Yanbian University.
- Zhang, Y., Wang, X., Liu, B., Liu, Q., Zheng, H., You, X. and Li, F. (2020). Comparative study of individual and Co-Application of biochar and wood vinegar on blueberry fruit yield and nutritional quality. *Chemosphere*. 246: 125699.
- Zheng, H., Wang, Z., Deng, X., Herbert, S., Xing, B. (2013) Impacts of adding biochar on nitrogen retention and bioavailability in agricultural soil. *Geoderma*. 206: 32–39.
- Zheng, H., Wang, X., Chen, L., Wang, Z., Xia, Y., Zhang, Y., Wang, H., Luo, X., Xing, B. (2018). Enhanced growth of halophyte plants in biochar-amended coastal soil: roles of nutrient availability and rhizosphere microbial modulation. *Plant Cell Environ*. 41: 517-532.
- Zhou, L., Jiang, E. C. and Li, B. S. (2009). Effect of wood vinegar on seed germination and water implantation of corn. *Journal of Northeast Agricultural University* (English Edition). 16(2): 6-11.
- Zulkarami, B., Ashrafuzzaman, M., Husni, M. O. and Ismail, M. R. (2011). Effect of pyroligneous acid on growth, yield and quality improvement of rockmelon in soilless culture. *Australian Journal of Crop Science* 5(12): 1508-1514.

