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Effect of Foliar Spraying with Wood Vinegar on the Growth and Productivity of Potatoes under Different Levels of Mineral Fertilization

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ABSTRACT

The research was conducted at the Homs Research Center during the 2022–2023 agricultural seasons, aiming to study the effect of foliar spraying with different concentrations of wood vinegar under varying levels of mineral fertilization, applied at a rate of three sprays during the season. The experiment was designed using a randomized complete block design and included nine treatments. (Foliar spraying with wood vinegar 3% and 6% and mineral fertilization 50% and 100% of the fertilizer recommendation combined treatments between them). The results showed significant superiority of the plants treated with 6% wood vinegar along with either the full or half of the recommended dose of NPK fertilizers (in terms of plant height and number of stems). The positive effect of wood vinegar on vegetative growth indicators contributed to improving productivity and quality parameters (number of small, medium, and large tubers; yield; starch content). The treatment involving 6% wood vinegar with the full recommended NPK dose resulted in (0.67, 3.67, 2.33 tubers/plant; 4.12 kg/m²; 9.00%, respectively), with no significant differences compared to the same concentration with half the NPK dose (0.83, 3.33, 2.33 tubers/plant; 4.03 kg/m²; 8.83%) over the untreated and unfertilized control.

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INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the globally significant strategic crops belonging to the Solanaceae family. It is considered a substitute for grains, which have seen significant price increases in recent years, thereby necessitating increased attention to this crop to boost its production. In Syria, potato is among the most important vegetable crops, widely cultivated across most governorates. The cultivated area reached 27,484 hectares, yielding approximately 647,349 tons, according to the Syrian Ministry of Agriculture (Annual Agricultural Statistical Abstract, 2022).

Nutritionally, potatoes are a staple in most countries due to their high levels of energy, proteins, vitamins, and minerals (Mathur, 2003; Muthoni and Nyamongo, 2009). The dry matter content ranges between 15–29%, with starch comprising 15–52%, proteins 1–2%, and minerals up to 1%, mainly potassium salts, which constitute about 70% of total minerals. Other elements include phosphorus, sodium, iron, manganese, calcium, and magnesium (Krylova et al., 2000) Potatoes are a major source of carbohydrates and vitamins, and their importance lies in their contribution to food security, their wide industrial uses (such as starch production), and their significant economic value to farmers. Potatoes grow in cold to temperate climate conditions. The optimal growing temperature is between 15 and 20 degrees Celsius. Light, well-drained soils, such as sandy loam, are preferred to prevent tuber rot. The optimal soil pH ranges from 5.0 to 6.5 (slightly acidic to neutral).

The random use of chemical fertilizers and hormones has contributed to the spread of cardiovascular and cancerous diseases (Zhu et al., 2021) and caused harmful environmental effects such as global warming, groundwater pollution, and ozone layer depletion (Crews and Peoples, 2004). These compounds also affect plants by reducing antioxidant content and increasing nitrate accumulation (Alessa et al., 2017). Therefore, researchers have shifted toward using natural extracts and substances as a safe, sustainable, cost-effective alternative to enhance plant growth, productivity, and stress tolerance, thus reducing chemical fertilizer use and environmental pollution (Kalsoom et al., 2020).

Among the most popular natural substances currently is wood vinegar (pyroligneous acid), an organic byproduct of carbonizing tree branches, crop residues, and wood scraps. It is a reddish-brown, high-density organic liquid composed of approximately 70% water, 5–10% organic acids by weight, and over 200 organic compounds including aldehydes, ketones, alcohols, phenols, and nitrogenous compounds (Wei et al., 2010; Pimenta et al., 2018).

Wood vinegar is widely used in medicine, food, and particularly agriculture (Cai et al., 2012; Dissatian et al., 2018). It increases soil fertility, reduces fertilizer needs by up to 50%, and enhances the soil's physical and chemical properties (Abdolahipour and Highchair, 2020; Del Buono, 2021). It stimulates enzyme activity, reduces ammonia loss, alleviates heavy metal toxicity (Liu et al., 2018), adjusts pH, and improves nutrient availability (Seo et al., 2015).

It is also used as an insect repellent, soil conditioner, and foliar fertilizer (Mohan et al., 2006; Jung, 2007; Wei et al., 2010). Studies indicate its importance in improving seed germination, accelerating the growth of roots, stems, leaves, and flowers (Kulkarni et al., 2006; Mungkunkamchao, 2013). Wood vinegar enhances drought tolerance in potatoes by promoting a developed root system for water absorption (Bengough et al., 2011). During drought, root proteins related to energy metabolism accumulate, increasing energy demand (Yu et al., 2017), while proteins involved in cell wall biosynthesis, amino acid metabolism, secondary metabolism, and signaling adjust the plant's drought response (Faghani et al., 2015; Agrawal et al., 2016; Yu et al., 2017; Prinsi et al., 2018).

The biological and physicochemical activity of wood vinegar depends on factors such as biomass composition, pyrolysis system, and production method (Theapparat et al., 2014).

Studies by Ofoe et al. (2024) demonstrated that foliar spraying with 2% wood vinegar plus the full NPK dose on tomato plants significantly increased leaf chlorophyll content (A, B, and total) and fruit number compared to lower concentrations and controls. Similar results observed tomato fruit quality (Maach, 2021; Ofoe, 2024).

Vannini et al. (2021) and Ye et al. (2022) noted that foliar spraying at 2% wood vinegar with full NPK significantly enhanced chlorophyll content, improving photosynthesis.

Becagli et al. (2023) reported that foliar application of 3 ml/L wood vinegar on faba beans increased pod number and yield, and Essa et al. (2023) found that 4 ml/L improved plant height, seed weight, and content of phosphorus, potassium, protein, and carbohydrates on the bean plant in bean plants.

Siriwardena et al. (2020) tested various concentrations (0.25–1%) on eggplant and observed significant increases in plant height, leaf number, stem girth, and branching at 1% concentration compared to control.

Studies also confirm that mineral fertilization positively affects yield quantity and quality due to the fast-acting nature of chemical fertilizers containing essential nutrients (Saeed et al., 2012). Fadhili (2011) found that applying NPK at 240, 120, 400 kg/ha improved potato yield to 50.98 t/ha, increased leaf nutrient content, and raised tuber dry matter and starch content.

Salimany and Fadhili (2010) reported that combining 33% organic and full mineral fertilization increased stem number and dry matter. Abbas and Hussein (2016) found that combining 32 t/ha organic fertilizer with full mineral fertilizer achieved the highest tuber germination rate and reduced the percentage of non-marketable tubers.

Thus, this study explores using wood vinegar as a promising, locally available, easy-to-prepare material derived from tree pruning residues, aiming to find sustainable alternatives for continued agricultural production while reducing dependency on costly chemical inputs tied to fuel prices.

The objective of this research was to investigate the effects of foliar application of different wood vinegar concentrations under two levels of mineral fertilization on the growth and productivity of the spring potato cultivar "Spunta", and to determine the optimal concentration.

MATERIALS and METHODS

Plant Material

The experiment used the potato cultivar "Spunta" a Dutch late-maturing variety (100–110 days from planting). It produces large, oval-shaped tubers preferred in the market, with yellow skin and light-yellow flesh. The eyes are semi-deep, and plants typically produce large-sized tubers with high yield, especially in the spring season.

Experiment Site

The experiment was conducted at the Homs Research Center during the 2022–2023 agricultural seasons. The soil at the site is reddish-brown clay, slightly acidic to neutral, low in organic matter, and rich in available nitrogen, phosphorus, and potassium (Table 1).

Table 1. Selected soil properties at the experimental site

Organic Matter (%)	Available N (mg/kg)	Available K (mg/kg)	Available P (mg/kg)	pH	Sand (%)	Silt (%)	Clay (%)
1.6	19.1	350	20.8	6.7	16	20	64

Experimental Treatments

T1: 3% wood vinegar foliar spray without NPK fertilization, **T2:** 3% wood vinegar foliar spray + 100% recommended NPK, **T3:** 3% wood vinegar foliar spray + 50% recommended NPK, **T4:** 6% wood vinegar foliar spray without NPK, **T5:** 6% wood vinegar foliar spray + 100% recommended NPK, **T6:** 6% wood vinegar foliar spray + 50% recommended NPK, **T7:** 100% recommended NPK only, **T8:** 50% recommended NPK only and **T9 (Control):** No foliar spray or mineral fertilization.

Foliar Spray Application Method

The wood vinegar was sprayed on the foliage three times during the growing season:

1. **First spray:** 10 days after full emergence

2. **Second spray:** Two weeks after the first
3. **Third spray:** At the tuber initiation stage, two weeks after the second

Commercial Wood Vinegar Used

The product used was "Sika" wood vinegar—a 100% safe organic liquid with high density and reasonable cost. Its composition includes 80–90% water and about 200 natural organic compounds, such as: Acetic acid: 426.5 ppm, Methanol: 1174 ppm, Phenol: 1.1%, Acetone: 247.4 ppm, Formic acid: 410.6 ppm, Butyric acid: 49.5 ppm and Propionic acid: 257 ppm (Pimenta et al., 2018).

Land Preparation and Planting

The soil was plowed twice at a depth of 30–35 cm. Before the final plowing, mineral fertilizers were applied according to the Ministry of Agriculture's recommendations (180 kg N, 90 kg P, and 90 kg K per hectare). Based on soil analysis, the following fertilizers were applied at two levels (50% and 100%) according to each treatment:

Urea (46% N): 5.85 g/plant

Triple superphosphate (46% P): 8.5 g/plant

Potassium sulfate (50% K): 6.5 g/plant

The soil was then formed into single rows spaced 75 cm apart. Sprouted whole tubers (weighing 50–60 g) were planted at a depth of 8 cm and spaced 35 cm apart along the row on the specified dates 1/3 Each treatment was planted in an experimental plot containing 3 rows (each row being 105 cm long and containing 3 plants, 9 plants per treatment). The necessary service operations were provided (weeding twice, the first time after germination and the second time after a month, and irrigation once a week until harvest, and no disease control operation was carried out).

Harvesting

Plants were defoliated (irrigation stopped) ten days before harvest upon observing maturity signs (yellowing and drying of the foliage). Harvesting was performed for both seasons on the specified dates 1/7. The yield was collected separately for each replication and treatment.

Measured Parameters

Vegetative Growth Parameters: Measured at the full vegetative growth stage (flowering stage):

Plant Height (cm): Measured from the soil surface to the top of the plant

Number of Stems per Plant

Yield Parameters

Number of Tubers per Plant: Tubers were classified by weight:

Small: <35 g

Medium: 35–80 g

Large: >80 g

Yield (g/m²): Calculated from the total weight of tubers per experimental plot after drying

Relative Fertilizer Efficiency (RFE)

Calculated using the equation (Barakat et al., 1991):

RFE=(Yield from treatment-Yield from control fertilizer) / Yield from treatment) × 100

Chemical Analyses

Total Soluble Solids (TSS): Measured using a refractometer

Starch Content (%): Determined using by AOAC (1970) method:

Starch %=17.55+0.891 × (Dry Matter %–24.18)

Experimental Design and Statistical Analysis

The experiment followed a randomized complete block design with nine treatments and four replicates. Data were analyzed, and values for the coefficient of variation (CV) and least significant difference (LSD) at 5% and 1% significance levels were calculated using GenStat 12th Edition.

RESULTS and DISCUSSION

Plant Height (cm): Table 2 shows that Treatment 5 (6% wood vinegar + 100% NPK) achieved the greatest average plant height (68.5 cm), significantly surpassing all other treatments. Treatment 6 (6% + 50% NPK) came next with 59.17 cm, also significantly higher than Treatments 1, 4, 8, and 9. All treatments showed higher plant height than the unfertilized and unsprayed control (Treatment 9: 45.50 cm) except Treatment 1, which showed no significant difference (50.17 cm).

Number of Stems per Plant: Treatments 2, 3, 5, and 6 showed a significantly higher number of stems (3.83, 3.50, 3.83, and 3.83 stems/plant, respectively) compared to Treatments 1 and 9 (2.17 and 2.00 stems/plant). No significant differences were found with other treatments.

Table 2. Effect of foliar spraying with wood vinegar on vegetative growth indicators of "Spunta" potato under different mineral fertilization levels

Treatments	Treatment Description	Plant Height (cm)	Stems/Plant
1	3% wood vinegar + 0% NPK	50.17 ^{de}	2.17 ^{bc}
2	3% wood vinegar + 100% NPK	58.17 ^{bc}	3.83 ^{a}
3	3% wood vinegar + 50% NPK	55.00 ^{bcd}	3.50 ^{a}
4	6% wood vinegar + 0% NPK	52.83 ^{cd}	3.00 ^{abc}
5	6% wood vinegar + 100% NPK	68.50 ^{a}	3.83 ^{a}
6	6% wood vinegar + 50% NPK	59.17 ^{b}	3.83 ^{a}
7	100% NPK only	53.50 ^{bcd}	3.17 ^{ab}
8	50% NPK only	52.33 ^{cd}	3.00 ^{abc}
9	Control (no spray, no fertilizer)	45.50 ^{e}	2.00 ^{c}

LSD 5%: Plant Height = 6.260, Stems/Plant = 1.047 CV: Plant Height = 9.8%, Stems/Plant = 12.5%. *Different letters indicate statistically significant differences at the 5% level (P<0.05).*

The data in Table 3 indicates the following:

Number of Small Tubers per Plant: Control treatment (9) produced the largest number of small tubers (4.50 tubers/plant) with significant differences over all treatments except treatment (8, 1), while treatment (5, 6) achieved the lowest number (0.67, 0.83 tubers/plant, respectively).

Number of Medium Tubers per Plant: Treatment 5 again had the highest number of medium-sized tubers (3.67/plant), followed closely by Treatment 6 (3.33/plant), both significantly higher than all other treatments.

Number of Large Tubers per Plant: Treatments 5 and 6 produced the largest tubers (2.33/plant), significantly more than Treatments 1, 8, and 9 (with Treatment 9 having the lowest: 0.50/plant).

Yield (kg/m²): Treatments 5 and 6 yielded 4.12 kg/m² and 4.03 kg/m², respectively, significantly outperforming all other treatments. The control (Treatment 9) had the lowest yield (2.42 kg/m²).

Relative Fertilizer Efficiency (%): The highest RFE was recorded in Treatments 5, 6, and 7, with values of 41.26%, 39.95%, and 39.5%, respectively.

Table 3. Effect of wood vinegar foliar spray on yield indicators of "Spunta" potato under different levels of mineral fertilization

Treatments	Treatment Description	Small Tubers	Medium Tubers	Large Tubers	Yield (kg/m^2)	RFE (%)
1	3% wood vinegar + 0% NPK	4.00 d	2.00 d	0.67 c	2.73 e	11
2	3% wood vinegar + 100% NPK	2.00 b	2.83 bc	2.33 a	3.83 b	63.81
3	3% wood vinegar + 50% NPK	2.00 b	2.67 bcd	2.17 ab	3.67 bc	34.1
4	6% wood vinegar + 0% NPK	2.67 bc	2.50 cd	2.00 ab	3.50 c	30.85
5	6% wood vinegar + 100% NPK	0.67 a	3.67 a	2.33 a	4.12 a	41.26
6	6% wood vinegar + 50% NPK	0.83 a	3.33 ab	2.33 a	4.03 a	39.95
7	100% NPK only	2.00 b	2.50 cd	2.00 ab	4.00 c	39.5
8	50% NPK only	3.67 cd	2.17 cd	1.50 b	2.95 d	17.97
9	Control (no spray, no fertilizer)	4.50 d	1.00 e	0.50 c	2.42 f	–

LSD 5%: Small Tubers = 1.021, Medium = 0.7190, Large = 0.7868, Yield = 0.7979 CV: Small = 8.9%, Medium = 9.4%, Large = 10.15%, Yield = 4.8%. *Different letters indicate statistically significant differences at the 5% level (P<0.05).*

The results in Table 4 show the following:

Total Soluble Solids (%): Treatments 5, 6, and 2 recorded the highest TSS values (19.65%, 19.64%, and 19.62%, respectively), significantly outperforming the rest. The control (Treatment 9) had the lowest TSS (11.21%), with no significant difference from Treatments 1 and 7.

Starch Content (%): Treatment 5 had the highest starch content (9.00%), significantly higher than Treatments 1, 4, 7, 8, and 9. The control (7.17%) showed the lowest value.

Table 4. Effect of wood vinegar foliar spray on TSS and starch content in "Spunta" potato tubers

Treatments	Treatment Description	Starch (%)	TSS (%)
1	3% wood vinegar + 0% NPK	7.33 c	11.23 c
2	3% wood vinegar + 100% NPK	8.67 ab	19.62 a
3	3% wood vinegar + 50% NPK	8.50 ab	19.32 b
4	6% wood vinegar + 0% NPK	7.50 c	11.23 c
5	6% wood vinegar + 100% NPK	9.00 a	19.65 a
6	6% wood vinegar + 50% NPK	8.83 ab	19.64 a
7	100% NPK only	8.33 b	11.33 c
8	50% NPK only	7.50 c	11.23 c
9	Control (no spray, no fertilizer)	7.17 c	11.21

LSD 5%: Starch = 0.6470, TSS = 0.2615, CV: Starch = 6.9%, TSS = 12.5%. *Different letters indicate statistically significant differences at the 5% level (P<0.05).*

DISCUSSION

The results demonstrate the importance of foliar spraying with wood vinegar—especially at a 6% concentration—combined with either the full or half of the recommended mineral NPK fertilization, in improving vegetative growth, productivity, and quality traits of the "Spunta" potato cultivar.

Spraying at the 6% concentration led to significant increases in plant height and stem number, in agreement with findings by Kulkarni et al. (2006) and Mungkunkamchao (2013). This growth enhancement can be attributed to the richness of wood vinegar in essential nutrients such as nitrogen, calcium, and potassium, in addition to biologically active compounds that stimulate nutrient uptake by roots and enhance chlorophyll biosynthesis (Ofoe et al., 2024).

The beneficial effects of wood vinegar are likely due to a combination of organic acids, especially acetic acid and other compounds such as phenols and ketones, which are known to stimulate physiological responses in plants (Liu et al., 2021; Zhou et al., 2021), thereby improving vegetative growth indicators.

Applying wood vinegar along with the full or half recommended NPK dose also affected tuber size distribution and increased yield particularly with the 6% concentration without significant statistical differences between the two fertilizer levels. Although the exact mechanism behind the yield increase is not fully understood, it may relate to enhanced chlorophyll content in the leaves, improved photosynthesis (Grewal et al., 2018), and increased carbohydrate accumulation, which is later transferred to the storage organs (tubers) (Liu et al., 2019). This results in improved tuber quality, particularly starch content, as supported by Essa et al. (2023) and Becagli et al. (2023).

Recent studies have shown that karrikins, compounds found in wood vinegar, act similarly to plant hormones especially gibberellins and cytokinins and thus play a role in regulating plant growth and increasing yield (Van Staden et al., 2004).

Mineral fertilizers also play an essential role in plant development. Nitrogen promotes chlorophyll and protein synthesis, potassium enhances productivity and tuber quality by indirectly influencing many physiological processes (such as photosynthesis and ATP formation), and calcium facilitates nutrient uptake and cell elongation, thereby supporting overall plant growth (Tripathi et al., 2014; Scherwinski-Pereira et al., 2009).

CONCLUSION and RECOMMENDATIONS

Apply foliar spraying of wood vinegar at a 6% concentration along with half of the recommended NPK dose to improve vegetative growth and productivity of the spring potato cultivar “Spunta”. Using wood vinegar on other crops and in different concentrations.

Conflict of Interest

The authors have declared that there are no competing interests.

Authors’ Contribution

The concept was designed by FW and RAl-B. The field experiment was carried out by FW. Statistical analysis was performed by OAl-A and RAl-B. The discussion of the results was conducted by RAl-B and OAl-A. Laboratory analysis was carried out by AM.

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