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Efficacy of Fermented Garlic and Vinegar-Based Biopesticide for the Management of Sweetpotato Wilt Caused by *Fusarium oxysporum* f. sp. *batatas*

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vinegar formulation
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Trichoderma harzianum
wood vinegar
sweetpotato wilt

Abstract

This study aimed to determine possible biopesticides against *Fusarium* wilt in sweetpotato using locally available materials. The fungicidal efficiency of fermented garlic and vinegar combinations were tested against *Fusarium oxysporum* f. sp. *batatas* through bioassay, as a soil amendment, and as a spray on infected field plants. Three different local kinds of vinegar, namely sweetpotato vinegar, coconut water (*sukang puti*) and cane vinegar produced comparable inhibition zones in vitro. Garlic and wood vinegar combination produced the least inhibition zone against the fungus but was the most effective soil amendment. Soil with *Trichoderma harzianum* recorded the highest herbage weight and length but did not translate to storage root yield. Instead, garlic and wood vinegar or sweetpotato vinegar had the highest storage root yield. Its efficacy was comparable with other amendments such as *Trichoderma harzianum* and lime. The soil amendments enhanced herbage and root yield in the study despite favorable conditions for disease development. When used as a spray, garlic extract combined with either wood vinegar, sweetpotato, coconut water, or cane vinegar was found effective in controlling *Fusarium* wilt, as verified in two trials giving more than 50% disease control compared to untreated plants. Results showed that fermented garlic, regardless of local vinegar formulation, is an effective biopesticide in managing *Fusarium* wilt of sweetpotato.

Introduction

As a traditional food, sweetpotato is of high social importance as part of a culture, identity, gastronomic heritage, and economic growth. Also, it contributes to the development, diversification, and sustainability of many rural areas, providing a greater food variety and ensuring income for locals (Galanakis, 2019). However, the average yield in 2014 was below the national average farm productivity by 5.5% (Bureau of Agricultural Statistics [BAS], 2015).

One of the primary reasons for the low productivity is the major devastation brought by Fusarium wilt disease (*Fusarium oxysporum* f.sp. *batatas*). This cause had been confirmed based on geographical surveys, diagnostic procedures, and the culture of the pathogen. Yap-eo (2015) identified sweetpotato *Fusarium* wilt in Asipulo, Ifugao initially speculated as "*tungro*" and was widespread in swidden fields in 2012 and worsened the following years. Similar incidence was observed in Barangays Ekip and Pito of Bokod, Benguet, and in Mountain Province, where farmers claimed that their sweetpotato roots were decreasing in size and drying up (Yap-eo, 2015). These disease manifestations in sweetpotato simultaneously occurred in different parts of the region from 2012 to 2016. More disturbing are the ecological and socio-cultural effects on the livelihood of the indigenous communities (Batani et al., 2016).

Due to the worsening situation, sweetpotato farmers sought help from the Department of Agriculture-Corillera Administrative Region (DA-CAR). DA-CAR then sought technical assistance from the Northern Philippines Root Crops Research and Training Center at Benguet State University to help the farmers identify and give possible solutions to the sweetpotato *Fusarium* wilt problem. Hence, a collaborative project was implemented among the local government units, farmers/households, technicians, DA-CAR-RFO, and BSU-NPRCRTC. This study was conducted to determine effective ways of minimizing or managing sweetpotato *Fusarium* wilt using locally available materials.

Soil amendments are a widespread means to control diseases caused by soil-borne pathogens like *Fusarium* wilt. Due to its antimicrobial action, garlic can be a possible solution (Teranoto et al., 2010). It has natural fungicidal and pesticide properties that work effectively to control pests and makes an excellent, economical, non-toxic biological pesticide for use in agriculture (Patterson, 2014 as cited by Magwenya et al., 2016). It accelerates the growth of roots, stems, tubers, flowers, and fruits (Landacan & Perez, 2009).

Garlic fresh extract was shown to inhibit the growth of 14 species of bacteria, including *Staphylococcus aureus, Klebsiella pneumonia*, and *Escherichia coli*. Likewise, it acts as a fungicide against *Candida albicans* and can kill protozoans and viruses. Its antimicrobial actions could be attributed to the organosulfur compounds it contains, such as S-allylcysteine, diallyl sulphides, allicin, and its derivatives (Tapiero et al., 2004).

Additionally, wood vinegar, also known as pyroligneous acid, improves soil quality, eliminates pests, and controls plant growth, but it is slightly toxic to fish and very toxic to plants if overapplied. The use of organic soil amendments such as wood vinegar/mokusako, lactic acid bacterial serum, and fermented fruit juice significantly reduced *R. solanacearum* population almost by 50% in just two weeks, but greenhouse results need to be validated in the field (Landacan & Perez, 2009). On the other hand, *Trichoderma* strains have long been recognized as biological agents for the control of plant disease and for their ability to increase root growth and development, crop productivity, resistance to abiotic stresses, and uptake and use of nutrients (Ranasingh et al., 2006). Harman (2000) describes that it is effective against fungi like *Fusarium, Phytopthora, Sclerotia*, and *Rhizoctonia*, which induces resistance in plants and ethylene production, hypersensitive responses, and other defense-related reactions in plant cultivars. Further, colonization by *T. harzianum* readily enhances root growth development, crop productivity, and resistance to abiotic stresses through enhancement of mineral flow and absorption.

The abovementioned literature show that locally available materials such as garlic and wood vinegar as biopesticide and *T. harzianum* as a soil amendment could be used to control soil-borne pathogens. This study determined the efficiency of locally available materials in controlling or managing sweetpotato *Fusarium* wilt (*Fusarium oxysporum* f.sp. *batatas*).

Materials and Methods

Bioassay of Different Vinegar-based Garlic Mixture Against *Fusarium oxysporum* f. sp. *batatas*

Fermented garlic in strawberry vinegar was found effective against Fusarium wilt of garden pea (Villanueva et al., 2015). From this result, the efficacy of other commercial vinegar was used as a mixture base to prepare garlic mixture against sweetpotato *Fusarium* wilt. The bioassay was conducted in the laboratory with the following treatments:

Treatments	Vinegar formulations
T1	Distilled Water (Positive control)
T2	Garlic + Distilled water (1:1)
T3	Garlic + Sweetpotato vinegar (commercial) (2:1)

T4	Garlic + *Sukang puti* (fermented coconut water, commercial) (2:1)
T5	Garlic + Sugar cane vinegar (2:1)
T6	Garlic + Wood vinegar (2:1)

The penicillin disc method in solidified potato dextrose agar was used (Wheat, 2001). The different treatment combinations with garlic and the positive control (T1) using distilled water were prepared separately and labeled accordingly. Garlic + distilled water (T2) was prepared using a 1:1 equal ratio of garlic and distilled water. For garlic fermented with vinegar from sweetpotato (T3), coconut water (T4), cane (T5), and wood vinegar (T6), the ratio used was 2:1, where two garlic and one vinegar combination was used. A two-week-old pure culture of *Fusarium oxysporum* f.sp. *batatas* was scraped from the culture plate using L-rod shaped capillary tube and distilled water. High-density spores (1.0x108) at 1ml per plate were inoculated. Then a pre-cold melted potato dextrose agar (45ºC) was poured over and then with gentle agitation for even distribution of medium with the fungal spores around the plates. The medium was allowed to solidify. There were two plates assigned for each treatment which also represent their replications. Two penicillin discs were dipped in each treatment solution for 30 sec. and then placed at equal distances in the center of the plate. Penicillin discs were used in the assay to ensure that the solution is absorbed easily, thickens, and retains the solution for a longer period or until the end of the incubation period of 3 days or longer. Measurement of inhibition zone was done after 72 hrs incubation period at 25-30ºC using a foot rule in millimeter (mm). The experiment was laid out in a completely randomized design (CRD) with two replications. ANOVA and LSD were used in post hoc analysis using the Statistical Tool for Agricultural Research (STAR).

Soil Amendments Study Under Greenhouse Condition

The study was conducted under greenhouse conditions using naturally infested soil. Fifteen pots with 152mm x 254mm in diameter were used per treatment (3 replications with 5 pots per replication), planted with two cuttings of tissue-culture derived plants with six nodes. The selection of amendments used in the study was based on their effectiveness in managing bacterial wilt of potato (Landacan & Perez, 2005). The following treatments used were based on the promising result of the Landacan and Perez (2005) study:

Treatment	Soil amendments
T1	Chicken manure (100 ml vol/pot) (positive control)
T2	Dolomitic lime (1 tbsp/pot)
T3	Fermented garlic in sweetpotato vinegar (drench @ 80 ml/16L water)
T4	Fermented garlic in wood vinegar (drench @ 80ml/16L water)
T5	Trichoderma harzianum (mass produced in rice bran @ 2 tbsp/pot)
T6	Bacillus subtilis (Commercial formulation @ 240ml/16L water)
T7	Calcium hypochlorite (granulated bleach @ 1 tsp/pot)
T8	Fungicide (Propanocarb hydrochloride @ 64 ml/16L water) (synthetic pesticide control)

Chicken manure, lime, and calcium hypochlorite were applied only once using the rate indicated. The rest of the treatments were applied two times, one and two weeks after planting using the rate indicated.

Sweetpotato cultivar 'Immitlog' was used because it was susceptible to *Fusarium* wilt and short-maturing. The cultivar was planted two days after treatment application (except Calcium hypochlorite treatment which was planted a week after application). The second application was made two weeks after the initial. Before potting the soil, an initial assessment of *Fusarium* population density and soil pH was taken using a selective medium and pH meter, respectively. Daily temperature and relative humidity at 9:00 AM and 3:00 PM in the greenhouse were monitored and recorded using a digital wireless thermometer and hygrometer. Extreme temperature and humidity may affect the growth of the soil amendments applied. Soil samples were also taken at monthly intervals primarily to monitor changes in soil pH. The initial population density (colony counts) of the naturally infected soil used was taken. The monthly population count was not done due to the absence of $NaNO_3$, which was not purchased due to many restrictions. The effect of treatments to the pathogen under study was based on symptoms manifested on the leaves, vines, and roots. Root yield was recorded and stored for two months for weight loss and carry-over disease assessment in the storage based on symptoms and fungal growth retrieval.

Data gathered include number of days from planting to symptom expression; percentage disease incidence (no. of diseased plants/total no. of plants x 100) taken at first symptom appearance and at harvest; the weight of fresh root yield in grams, and percentage of roots that rot during storage after one month at room temperature (25ºC) (no. of rotten roots/total no. of roots x 100). The performance of the different treatments were compared using ANOVA and LSD as post hoc analysis, using the software Statistical Tool for Agricultural Research (STAR).

Cultural agronomic practices. Crop care and maintenance were practiced throughout the growing season, such as irrigation, weeding, and insecticide application. These agronomic practices were kept constant in all the treatments and replicates.

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On-farm Station Efficacy Verification on Standing Plants

Confirmation on the effectiveness of fermented vinegar-garlic mixture was conducted on-site farm station in two trials: November-December, 2017 (1st trial) using cvs. 'Immitlog' and 'Beniazuma' with 234 plants/cultivar and March-April, 2018 (2nd trial) using cvs. 'Immitlog' and 'Swerte' with 50 plants/cultivar. The fermented mixture of garlic + vinegar was sprayed over the canopy in a dripping manner to allow uniform distribution of the biopesticide solution both in the canopy and ground where plants had totally covered the aisles. Spraying was done weekly at 80ml of the mixture/16-liter water for two months on sweetpotato plants manifesting initial symptoms of the disease. Two sets of newly infected plants were observed, one for sprayed (bio-pesticide formulations) and the other unsprayed (tap water).

Disease incidence and disease control were used to verify efficacy. Percent disease incidence was assessed among plants sprayed and those unsprayed (control) using the following formula:

Disease Incidence (%)= (Number of plants in pots remained infected)/(Total plants/pot) x 100

Disease control was measured using the following formula:

$$\text{Disease Control (\%)} = \frac{\text{Untreated-Treated}}{\text{Untreated}} \times 100$$

Results and Discussion

Bioassay of Garlic-vinegar Combinations Against *Fusarium oxysporum* f. sp. *batatas*

Results of the study confirmed that garlic extract is an efficient antagonist of *Fusarium oxysporum* fsp. *batatas* and could be used as an alternative bio-pesticide. Freshly extracted garlic, in equal proportion with distilled water, produced the widest zone of inhibition (27.0mm) against Fusarium fungus in vitro (Table 1). Comparable evidence of growth suppression of the pathogen as expressed in the inhibition zone measurement was also recorded from garlic fermented to the three local kinds of vinegar, namely sweetpotato (T3), *sukang puti* (T4), and sugarcane (T5) with means of 7, 8 and 9, respectively. Wood vinegar produced the least inhibition zone (1.5mm) but relatively showed evidence of growth inhibition of the pathogen.

The findings of Hayat et al., 2016, strongly confirm the antifungal potential of garlic extracts and provide a basis for preparations of potent bio fungicide with broad-spectrum potential. Findings suggest that Phytoalexin allicin is the primary among various antifungal constituents of aqueous garlic extract and the abundance is diversified among different cultivars. The diversity in allicin abundance between various garlic cultivars offers a significant phytochemical trait to explore genetic diversity in garlic. Moreover, the research lay the foundation for conservation of garlic cultivars bearing strong allicin content for breeding purposes and pharmaceutical applications. The same authors further report that leaf disk bioassay allow elaborated evaluation of aqueous garlic extract as botanical fungicide in specialized horticultural situations where fungal infections hamper the production.

Furthermore, the antifungal potency of garlic is not solely attributed to the allicin content since many other organosulfur compounds maybe

Table 1

Bioassay on the Efficacy of Garlic Fermented with Different Vinegar Formulations

Vinegar formulations	Inhibition zone (mm)
T1- Distilled Water (positive control)	0.0
T2- Garlic + Distilled water (1:1)	27.0a
T3- Garlic + Sweetpotato vinegar(2:1)	7.5b
T4- Garlic + Sukang puti (2:1)	8.0b
T5- Garlic + Sugar cane(2:1)	9.0b
T6- Garlic + Wood vinegar(2:1)	1.5c

involved alongside (Hayat et al., 2016). These organic sulfur compounds are among the most important, versatile, and widely used groups of modern fungicides: thiram, ferbam, nabam, maneb, zineb, and mancozeb. These fungicides are derivatives of dithiocarbamic acid, which are toxic to fungi because they are metabolized to the isothiocyanate radical (--N=S). This radical inactivates the sulfhydryl groups (---SH) in amino acids and enzymes within the pathogen cells, thereby inhibiting the production and function of these compounds (Kuete, 2017).

The results also imply that locals can have options in selecting vinegar formulations that are abundant in their community. Fermented vinegar-based products have longer shelf life than water-based garlic preparation because they can be prepared in bulk and stored during the cropping season, ready-to-use without contamination as observed.

Acetic acid is created by fermenting alcohol. Household vinegar has a 5 percent solution of acetic acid made from the fermentation of plant products like grapes and apples. There are stronger concentrations of acetic acid available and even synthetically created acetic acid. All vinegar contains acetic acid, but not all acetic acid is vinegar (Lanotti, 2019). According to Abd-El-Kareem (2009), the most sensitive fungus to acetic acid vapors was *Rhizoctonia solani*, which was inhibited at 4 µl l. Accordingly, *Fusarium solani, Fusarium oxysporium* f. sp. *cucumerinum*, *Scleroitium rolfsii* and *Didymella melonis* were inhibited at 6 µl I, but complete inhibition of spore germination was obtained at 4 µl l in all tested fungi and at 10 ul I, complete inhibition of chlamydospores of *F. solani* and *F. oxysporum* f. sp. *cucumerinum* was obtained. Also accordingly, acetic acid significantly reduced the germination of resting stage of these fungi. *Sclerotia* of *S. rolfsii* were killed at 20 µl l of acetic acid vapor.

Soil Amendment Study under Greenhouse Condition

Soil pH, Fusarium oxysporum f. sp batatas Population, and Environmental Condition in the Experimental Greenhouse

Before the experiment setup, the initial soil pH was 5.5, and the initial population density of the infected soil used was 72 colonies/50mg soil. After a month, when treatments were already applied and planted with cuttings, a decreased soil pH was realized in all eight treatments ranging from pH 4.2-5.0 except the lime treated (T2) with increased pH from 5.5 to 6.2. However, at two months in treatment, a slight increase in pH was evident, ranging from 5.0-5.9 and highest in T2 at 6.6. After three months, soil pH in all treatments had slightly decreased, ranging from 4.7-5.4. Likewise, lime-treated soil (T2) had settled within the pH range of all treatments (Table 2).

Temperature and relative humidity (RH) were the two major weather components with vital roles in Fusarium wilt disease development. High temperatures and warm soils favor it. The optimum temperature for growth on artificial media is between 25-30°C, and the optimum soil temperature for root infection is 30°C or above (Khan et al., 2019). During the study, low RH inside the greenhouse was recorded at 9:00 am, with a monthly mean range from 42-59%. It peaked in the last weeks of January and dropped from February to May. The recorded afternoon RH ranged from 48-80%, with a similar trend in the morning. Temperatures inside the greenhouse ranged from 14-30°C, with lower values in January (Table 3).

Sweetpotato Wilt Disease as Affected by Soil Amendment Treatments

Symptoms of *Fusarium* wilt disease in sweetpotato include yellowing, wilting of leaves, and blackening of the stem base and laterals.

Table 2

Monthly Soil pH (February -April 2016)

Treatments	Monthly Soil pH		
	February	March	April
T1-Chicken manure	4.7	5.8	5.0
T2-Lime	6.2	6.6	5.0
T3-Garlic+SP vinegar fermented	4.6	5.4	5.0
T4-Garlic+Wood vinegar fermented	4.5	5.5	4.8
T5-*Trichoderma harzianum*	5.0	5.9	5.4
T6-*Bacillus subtillis*	4.4	5.1	4.9
T7-Calcium hypochlorite	4.4	5.1	4.8
T8-Propanocarb hydrochloride	4.2	5.0	4.9

Table 3

Mean Temperatures (°C) and Relative Humidity (%) Inside the Greenhouse during the Duration of the Experiment (January-May, 2017)

Months	Weeks gathered	Temperature (°C)		Relative Humidity (%)	
		9:00 AM	3:00 PM	9:00 AM	3:00 PM
January	3rd-4th	14.55	18.33	59.83	80.43
February	1st-5th	23.38	28.47	51.34	55.20
March	1st-5th	30.60	29.10	42.60	52.65
April	1st-4th	26.69	30.84	44.10	48.40
May	1st-3rd	31.4	29.06	53.00	55.10

Note: Digital wireless thermometer & hygrometer (Control Company brand) were used.

These occurred earliest at 28 days in chicken manure (T1) and fermented garlic+ sweetpotato vinegar (T3), at 35-days in *Bacillus subtilis* (T6) and Calcium hypochlorite (T7), and 100 days in *Trichoderma* (T5) and Propanocarb fungicide (T8). But plants in lime (T2) and fermented garlic+wood vinegar (T4) remained uninfected, indicating high efficiency in disease control. After 35 days, plants applied with *Bacillus subtilis* and Calcium hypochlorite exhibited the symptoms. Plants applied with *Trichoderma* and fungicide showed delayed disease development appearing only after three (3) months. Nevertheless, lime and fermented garlic+wood vinegar treatments exhibited no disease infection among the sample plants until harvest, indicating a high efficacy in disease control (Table 4). This finding corroborates Villanueva et al. (2015) that fermented garlic+vinegar (strawberry) effectively manages *Fusarium* wilt in organic garden pea production. On the other hand, Brierley (2008) cited that the forms of lime used (calcium oxide, hydroxide, carbonate, and silicate) encourage flocculation of colloidal particles, improving soil structure and drainage, which may explain disease reduction associated with the addition of lime. After 30 days of storage, infected fleshy roots were significantly least (0.67) in fungicide-treated (T8), followed by garlic+wood vinegar (T4) and *Trichoderma* (T5). The rest of the treatments had a comparable number of decayed roots with means ranging from 3.67 to 5.0 (Table 4).

Sweetpotato Yield Under Soil Amendment Treatments

In terms of yield, T5 (*Trichoderma harzianum*) gave the heaviest herbage weight (54.92g) and longest shoot (64.07cm), followed by T1 (chicken manure) at 32.26g and 56.47cm, respectively. T3 (Garlic+SP vinegar fermented) also has high herbage length of 56.28 but a low herbage weight. Herbage weight and length in other treatments range from 17–25g and 42–47cm, respectively. However, the herbage did not translate to the yield of storage roots. The heaviest yield was recorded from T4, T3, and T2 at 2.10, 1.97, and 1.80kg, respectively, and least in T7 (Calcium hypochlorite) (Table 5).

The study's findings align with the findings of Villanueva et al. (2015) that fermented garlic+ strawberry vinegar effectively manages *Fusarium* wilt in organic garden pea production. The study now confirmed that the use of fermented garlic+wood vinegar and lime are also effective in managing *Fusarium* wilt in sweetpotato production. The use of *Trichoderma harzianum* in the study has comparable anti-microbial activity against *Fusarium* wilt with commercial fungicide (Propanocarb hydrochloride).

Table 4

Fusarium Wilt Disease as Affected by Soil Amendment

Treatments	No. of days from planting to initial symptom expression	Disease Incidence (% Initial)	Disease Incidence (% Final, 119 DAP)	No. roots decayed (30 DAS)
T1-Chicken manure	28	6.67	20.0^{a}	5.00^{a}
T2-Lime	0	0	0^{b}	3.67^{abc}
T3-Garlic+SP vinegar fermented	28	6.67	10.0^{ab}	4.33^{ab}
T4-Garlic+Wood vinegar fermented	0	0	0^{b}	2.33^{bc}
T5-*Trichoderma harzianum*	100	3.33	3.33^{b}	2.33^{bc}
T6-*Bacillus subtillis* (commercial)	35	3.33	23.33^{a}	5.00^{a}
T7-Calcium hypochlorite	35	3.33	33.33^{a}	4.67^{a}
T8-Propanocarb hydrochloride (fungicide)	100	3.33	23.33^{a}	0.67^{d}

DAS – days after storage

Table 5

Yield as Affected by Soil Amendment

Treatments	Herbage weight (g)	Herbage length (cm)	Storage roots (No)	Storage roots (Kg.)
T1-Chicken manure	32.26^{b}	56.47^{a}	33.66^{a}	1.34^{ab}
T2-Lime	18.17^{bc}	47.24^{ab}	35.53^{a}	1.80^{a}
T3-Garlic+SP vinegar fermented	23.28^{b}	56.28^{a}	37.23^{a}	1.97^{a}
T4-Garlic+Wood vinegar fermented	16.65^{bc}	47.12^{ab}	31.98^{a}	2.10^{a}
T5-*Trichoderma harzianum*	54.92^{a}	64.07^{a}	34.62^{a}	1.30^{ab}
T6-*Bacillus subtillis* (commercial)	19.84^{b}	46.22^{b}	30.80^{a}	1.77^{a}
T7-Calcium hypochlorite	25.33^{b}	42.63^{b}	23.13^{ab}	1.20^{ab}
T8-Propanocarb hydrochloride (fungicide)	21.40^{b}	43.53^{b}	25.04^{ab}	1.63^{a}

Brierley et al. (2008) cited that different forms of lime (calcium oxide, hydroxide, carbonate, and silicate) encourage flocculation of colloidal particles, improving soil structure and drainage. This may explain the disease reduction of *Fusarium* wilt in the trial. On the other hand, *Trichoderma* strains have long been recognized as biological agents for the control of plant disease and for their ability to increase root growth and development, crop productivity, resistance to abiotic stresses, and uptake and use of nutrients (Ranasingh et al., 2006). As biochemical elicitors of disease resistance, *Trichoderma* strains are also known to induce resistance in plants. These compounds induce ethylene production, hypersensitive responses, and other defense-related reactions in plant cultivars. This result corroborates with the study of Ranasingh et al. (2006), in which the pathogen and the introduced biocontrol agent compete for the availability of space and nutrients. This study confirmed the biological activity of *Trichoderma harzianum* against *Fusarium oxysporum* f. sp. *batatas*. *Trichoderma harzianum* treated plants also produced the highest herbage weight and length, though this did not translate to greater storage root production. Moreover, the soil treated with Trichoderma harzianum showed improvement in soil pH. Root crops grow best in soil with a pH between 4.5 and 5.5. (Julie C. 2019). The increase in soil pH in the first and second months could be attributed to the amendment applied. As this amendment decomposes combined with the plants' interaction in the soil, the soil pH decreases over time. Temperature and relative humidity were the two major weather components with vital roles in *Fusarium* wilt disease development. As a saprophyte, *Fusarium* can survive in most soils and many types of environments. *Fusarium* wilt is a disease common in subtropical regions of the world. The optimum temperature for infection is around 30°C, as observed in the experimental greenhouse area, particularly from March to April as shown from the recorded weather data (Table 3). This temperature most likely contributed to the survival of *Fusarium oxysporum* f. sp. *batatas*. Still, the disease can develop at lower temperatures and across a wide range of soil moisture from 28 to 75%, but it is most damaging in low moisture and warm fields (O'Sullivan et al., 2014).

On-Farm Station Efficacy Verification

The efficacy of these fermented garlic-vinegar mixtures was tested on infected plants at the NPRCRTC Research Station. Since garlic fermented with three different household vinegars were comparable in their effectiveness based on the measurement of inhibition zones produced, any of the three mixtures were sprayed at a weekly interval in the two trials (November-December, 2017 and March-April, 2018).

In the first trial, sprayed plants showed 68 and 77% disease control in cultivars 'Beniazuma' and 'Immitlog', respectively, over the control plants (unsprayed), which succumbed to the disease at 100% infection. Similarly, the second trial showed 70 and 78% disease control for sprayed plants of 'Immitlog' and 'Swerte' cultivars, respectively (Table 6). Although higher disease incidences (50 and 60%) were observed from untreated plants, they were not completely devastated as in the first trial. These results confirm the greenhouse experiment results that the use of fermented garlic-vinegar mixtures controls the fusarium wilt disease. The plants sprayed with garlic-vinegar mixtures were able to overcome the infection and produce healthy vines. The result findings of Arzoo et. al., confirms that the use of garlic extract provided plant protection and reduced the disease intensity of *Fusarium oxysporum* in tomato with 8.93% infection compared to the untreated with 96.12% infection.

Conclusions

The fungal growth inhibitory effect of garlic, as a crude extract or fermented with commercial vinegars against *Fusarium oxysporum* f. sp. *batatas*, the causal pathogen of sweetpotato wilt, was evident in bioassay. In the greenhouse as a soil amendment, the controlling effect of garlic+wood vinegar was remarkable, showing 68-78% disease control when these three garlic vinegar formulations were sprayed alternately in infected field plants as biopesticides. Commercial vinegar formulations used are common household condiments that, when fermented with garlic, are easy to prepare and can considerably decrease wilt incidence; thus, they could be used to manage *Fusarium* wilt of sweetpotato under organic farming.

Table 6

Verification on the Effectiveness of Garlic-vinegar Fermented Mixture in Naturally Infected Plants on Station

Trials	Total no. plants	No. of infected plants	% Disease incidence	% Disease control
1st Trial				
Sprayed				
Immitlog	234	53	22.65	77.35
Beniazuma	234	75	32.05	67.95
Unsprayed				
Immitlog	234	234	100	0
Beniazuma	234	234	100	0
2nd Trial				
Sprayed				
Immitlog	50	15	30	70
Swerte	50	11	22	78
Unsprayed				
Immitlog	50	30	60	40
Swerte	50	25	50	50

Recommendations

The study recommends the use of either sweetpotato or wood vinegar combined with garlic in the management of sweetpotato *fusarium* wilt. Further, field study should be conducted to validate the result of the greenhouse on different cropping seasons.

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