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## Effect of NPK fertilizer, Wood vinegar and *Trichoderma hamatum* fungus on damping-off disease of tomato seedlings caused by *Fusarium solani*

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### Abstract:

*Fusarium solani* induced damping-off is an important limiting factor for tomato production in Iraq, and leads to severe epidemics with large stand losses. This research aimed to test the efficacy of organic NPK fertilizer, wood vinegar and bio-control fungus *Trichoderma hamatum* either sole or coupled application against disease incidence and seedling performance. The NPK fertilizer (18 g pot<sup>-1</sup>) was the best fertilizer treatment and resulted in the highest level of germination rate (80.55%), least seed rot incidence (19.45%) and minimum seedling mortality (9.63%). It also possessed better growth characteristics both among all endophytes tested, such as maximum height of seedling (6.602 cm), shoot dry weight (0.7657 g) and root dry weight (0.06214 g). Among wood vinegar concentrations, the 2% level was the most effective with germination (84.44%) and seed rot (15.56%) both reduced and lower percentage of seedling mortality (7.04%), as well as better growth attributes (seedling height 6.587 cm; shoot dry weight 0.7717 g; root dry weight 0.06237 g). With respect to fungal ratios, the T3:F0 treatment (pure *T. hamatum*) exhibited the best performance resulting in the highest germination percentage (91.67%), lowest seed rot incidence (8.33%) and most vigorous growth of seedlings (height 6.785 cm; shoot dry weight 0.8460 g; root dry weight 0.07582 g). In conclusion, *T. hamatum* and 2% wood vinegar combined with NPK at 18 g were observed to substantially contribute to disease control and the improvement of seedling vigor under our experimental condition, suggesting that these appeared promising in integrated management of tomato damping-off.

**Keywords:** wood vinegar, Tomato, *F. solani*, *T. hamatum*, NPK Fertilizer.

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تأثير سماد NPK وخنّ الخشب وفطر *Trichoderma hamatum* في مرض موت البادرات في شتلات  
الطماطم المتسبب عن فطر *Fusarium solani*

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### الخلاصة

يُعدّ مرض موت البادرات المتسبب عن فطر *Fusarium solani* أحد العوامل المحدّدة الرئيسة لإنتاج الطماطم في العراق، إذ يؤدي إلى حدوث أوبئة شديدة تترافق مع فقدان كبير في أعداد النباتات. هدفت هذه الدراسة إلى اختبار كفاءة سماد NPK العضوي، وخلّ الخشب، وفطر المكافحة الأحيائية *Trichoderma hamatum*، سواء استُخدمت بصورة منفردة أم بتطبيقات مزدوجة، في خفض نسبة الإصابة بالمرض وتحسين أداء البادرات. أظهر سماد NPK (بمعدل 18 غم أصيص<sup>-1</sup>) أفضل معاملة سمادية، إذ حقق أعلى نسبة إنبات بلغت (80.55%)، وأدنى نسبة لتعفن البذور (19.45%)، وأقل معدل لموت البادرات (9.63%). كما أظهر خصائص نمو متفوقة مقارنةً بجميع المعاملات الأخرى، تمثلت في أعلى ارتفاع للبادرات (6.602 سم)، وأعلى وزن جاف للمجموع الخضري (0.7657 غم)، وأعلى وزن جاف للجذور (0.06214 غم). وفيما يخص تراكيز خلّ الخشب، كان التركيز 2% هو الأكثر فاعلية، إذ حقق نسبة إنبات مرتفعة (84.44%)، وانخفاضاً في نسبة تعفن البذور (15.56%)، فضلاً عن انخفاض نسبة موت البادرات (7.04%)، إلى جانب تحسين صفات النمو، المتمثلة في ارتفاع البادرات (6.587 سم)، والوزن الجاف للمجموع الخضري (0.7717 غم)، والوزن الجاف للجذور (0.06237 غم). أما فيما يتعلق بنسب الفطر، فقد أظهرت معاملة (T3:F0 فطر *T. hamatum* النقي) أفضل أداء، إذ سجلت أعلى نسبة إنبات (91.67%)، وأدنى نسبة لتعفن البذور (8.33%)، وأكثر نمو حيوي للبادرات، تمثل في ارتفاعها (6.785 سم)، والوزن الجاف للمجموع الخضري (0.8460 غم)، والوزن الجاف للجذور (0.07582 غم).

وفي الختام، أظهرت نتائج الدراسة أن فطر *T. hamatum* وخلّ الخشب بتركيز 2%، مع إضافة سماد NPK بمعدل 18 غم، أسهمت بشكل ملحوظ في مكافحة المرض وتحسين حيوية البادرات تحت ظروف التجربة، مما يشير إلى أن هذه المعاملات تُعدّ واعدة في برامج الإدارة المتكاملة لمرض موت البادرات في الطماطم.

الكلمات المفتاحية: خلّ الخشب، الطماطم، *F. solani*، *T. hamatum*، سماد NPK.

## 1. Introduction

Tomato *Solanum lycopersicum* L. is a member of the Solanaceae family and one of the most important vegetable crops grown in most parts of the world. Its native habitat is Peru in South America and it has great economic importance, and is one of the most consumed crops (Wang et al., 2024). Tomatoes have a high nutritional value and contain important nutrients for humans, such as nitrogen, potassium, phosphorus, and other substances such as carbohydrates, proteins, fats, and vitamins such as vitamins A and C, as well as a group of phenolic compounds. They also contain pigments such as carotene and lycopene (Gerszberg et al., 2015). Tomatoes rank second in the world after potatoes and come first in Iraq due to the high consumption of tomatoes. Recent years have witnessed an increase in the cultivation of the crop, as the cultivated area globally reached 5.05 million hectares, and in Iraq the cultivated area reached 31.98 thousand hectares, with a production estimated at about 754.76 thousand tons in 2020 (F.A.O, 2022). The expansion of tomato cultivation in open and protected lands throughout the year has led to the emergence of many production-specific diseases due to the availability of environmental conditions suitable for the spread and development of the disease (Barone and Frusciante, 2007). The most important of these diseases is seed rot and seedling death, which is one of the most widespread diseases in most countries of the world. This disease causes great damage as it infects the seeds and causes them to rot and infects the seedlings and kills them either before or after they emerge from the soil. It has caused losses of up to 100% (Agrios, 2007). One of the most important fungi that cause seed rot and seedling death is *Fusarium* spp., as this fungus is found

in light sandy soils to dense clay soils, and soil diversity has a clear effect on fungal growth and the severity of infection (El-Abeid et al., 2024). *Fusarium solani* is one of the most common pathogens of the genus *Fusarium* spp., whose sexual phase is *Nectria haematococca*, which belongs to the sac fungi Ascomycota A (Hoh et al., 2022; Li et al., 2023). The fungus infects the roots, causing rot, especially in the middle and late stages of plant growth (Sui et al., 2024). *Fusarium solani* is one of the most abundant fungi in the soil, living as a saprophyte or facultative parasite on plants. It also tends to parasitize living plant tissue more than saprophyte, causing a range of diseases. It infects the roots of mature plants, causing their rot, as well as the death of seedlings (Al-Mansoury and Salih, 2023). *Fusarium solani* grows at temperatures ranging from 8.5-34.3°C, with a temperature of 29.3°C and a humidity of 40-80% being the optimum conditions for fungal growth (Yan and Nelson, 2022). Despite the high effectiveness of chemical pesticides in controlling plant diseases, their increasing and repeated use has led to the emergence of pest resistance and its impact on non-target organisms, in addition to its negative effects on human health (Sharma and Mohanty, 2025). As a result, ideas have turned towards searching for safer and more sustainable methods such as the use of plant extracts and control agents based on beneficial microorganisms such as the fungus *Trichoderma* spp. and the bacteria *Pseudomonas*, etc. (Lahlali et al., 2022). In present study, the efficacy of organic NPK fertilizer, wood vinegar, and biocontrol fungus *Trichoderma hamatum* in isolation and in combination was investigated in damping-off disease caused by *Fusarium solani* on tomato seedlings. In particular, the study aimed to ascertain the best fertilizer dose, wood vinegar concentration or fungal blend that increase seed germination, mitigate against seed rot and seedling mortality and ameliorate indicators of early growth in pot experiments. The aim was to find viable and environmentally friendly alternatives to chemical fungicides for control of tomato damping-off.

## 2. Materials and Methods

### 2.1. Preparation of Potato Dextrose Agar (PDA)

This medium was prepared by dissolving 39 g of the prepared agar powder, according to the manufacturer's instructions, in 1 liter of distilled water. The medium was sterilized, and the antibiotic amoxicillin was added. The medium was then poured into Petri dishes and stored in a refrigerator at 4°C until use. This medium was used for the cultivation of the pathogenic fungus *Fusarium solani* and the bioresistant fungus *Trichoderma hamatum*.

### 2.2. Isolation of the pathogenic fungus *Fusarium solani*

After collecting samples based on the common symptoms of the disease, namely wilting and root rot, 3-5 pieces (0.5 cm in size) were taken from the infected areas. The infected pieces were superficially disinfected with alcohol for 30 seconds, then washed with distilled water for 1 minute, followed by a 2% sodium hypochlorite solution for 3 minutes. The infected parts were then washed with distilled water for 5 minutes. The pieces were then cultured in Petri dishes containing PDA medium, with 4 pieces per dish and three replicates. The dishes were incubated at  $25 \pm 2^\circ\text{C}$  for 2-4 days. Afterward, the fungi that grew on the culture medium were purified by taking a small piece from the edge of the colony with a needle and placing these pieces in the center of the dish containing the PDA medium. The plates were placed in the incubator at a temperature of  $25 \pm 2^\circ\text{C}$  for 5-7 days, after which the morphological diagnosis of the fungus was performed.

### 2.3. Source of *Trichoderma hamatum*

The *T. hamatum* isolate was obtained from Professor Dr. Azhar Hamid Faraj and corresponds to the strain characterized by Altaie and Alwan(2014) .

### 2.4. Materials used in the study

**Table (1) Agricultural materials used in the study**

Name of the material	Production company	Origin	components
NPK organic fertilizer	Chemical Fertilizers Laboratory, College of Agriculture – University of Kufa	Iraq	Nitrogen, Phosphorus Potassium, calcium Hmic acid, Fulvic acid Organic acids
wood vinegar	Al-Amin Factory for Agricultural Materials Production	Iraq	Phenol 2-Methylphenol 3-Methylphenol Creosol Catechol 4-Ethylbiphenyl

### 2.5. Plastic pots experiment

A sand and peat moss mixture (1:1 ratio) was sterilized using an autoclave at 121°C and 15 psi pressure for one hour. The sterilization process was repeated the following day. The experiment was conducted under Shading house conditions at the College of Agriculture, University of Kufa. One kilogram of the soil mixture was placed in sterile bags. The soil was inoculated with the pathogenic fungus *Fusarium solani* and the biocontrol agent *Trichoderma hamatum* carried on millet seeds at a 1% concentration prior to planting. The soil was moistened with water and maintained under lath house conditions for 5 days, with an uninoculated control treatment included for comparison. The soil was then distributed into 5×7×3 cm pots with three replicates per treatment. NPK fertilizer was applied at rates of 16 g and 18 g, and wood vinegar was applied at concentrations of 2% and 4%. The plastic pots were sown with local tomato seeds obtained from the Department of Horticulture and Forestry - Iraq, following surface sterilization with 2% sodium hypochlorite and subsequent rinsing with sterile distilled water to remove sterilization residues. All treatments were lightly irrigated and covered with polyethylene bags, then maintained under lath house conditions for 14 days with irrigation as needed. The polyethylene covers were removed upon seedling emergence. The percentages of seed germination, seed rot, and seedling mortality (damping-off) were calculated.

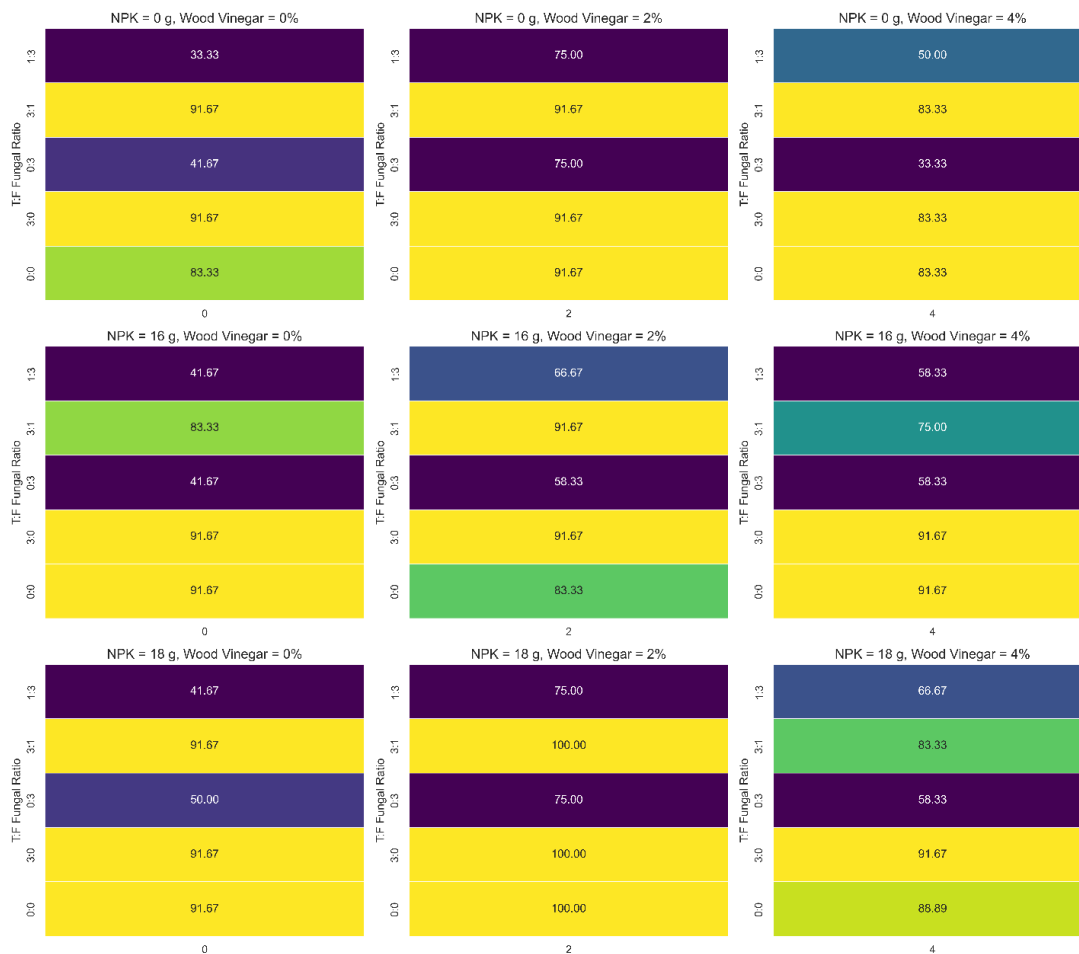
**germination percentage** = (Number of Germinated Seeds / Total Number of Seeds Sown) × 100

**Percentage of seedling death** = (Number of Dead Seedlings / Total Number of Initially Germinated Seedlings) × 100

## 3. Results and discussion

**3.1. The effect of organic NPK fertilizer wood vinegar concentrations, and mixing ratios between *F. solani* and *T.hamatum* fungi and measuring some growth indicators in plastic pots**

The results as shown Figure (1) showed that the highest percentage of tomato seed germination in the organic NPK fertilizer treatment appeared in treatment 18 gm where the percentage reached 80.55%, with significant differences from the rest of the treatments. The results of the effect of organic NPK fertilizer and wood vinegar concentrations indicated that the highest percentage of seed germination was in the treatment of 18 gm fertilizer and 2% wood vinegar concentration, where the percentage reached 90.00%, with significant differences from the rest of the treatments.



Each number in the table represents the average of three replicates\* =

F= *Fusarium solani*      T= *Trichoderma hamatum*

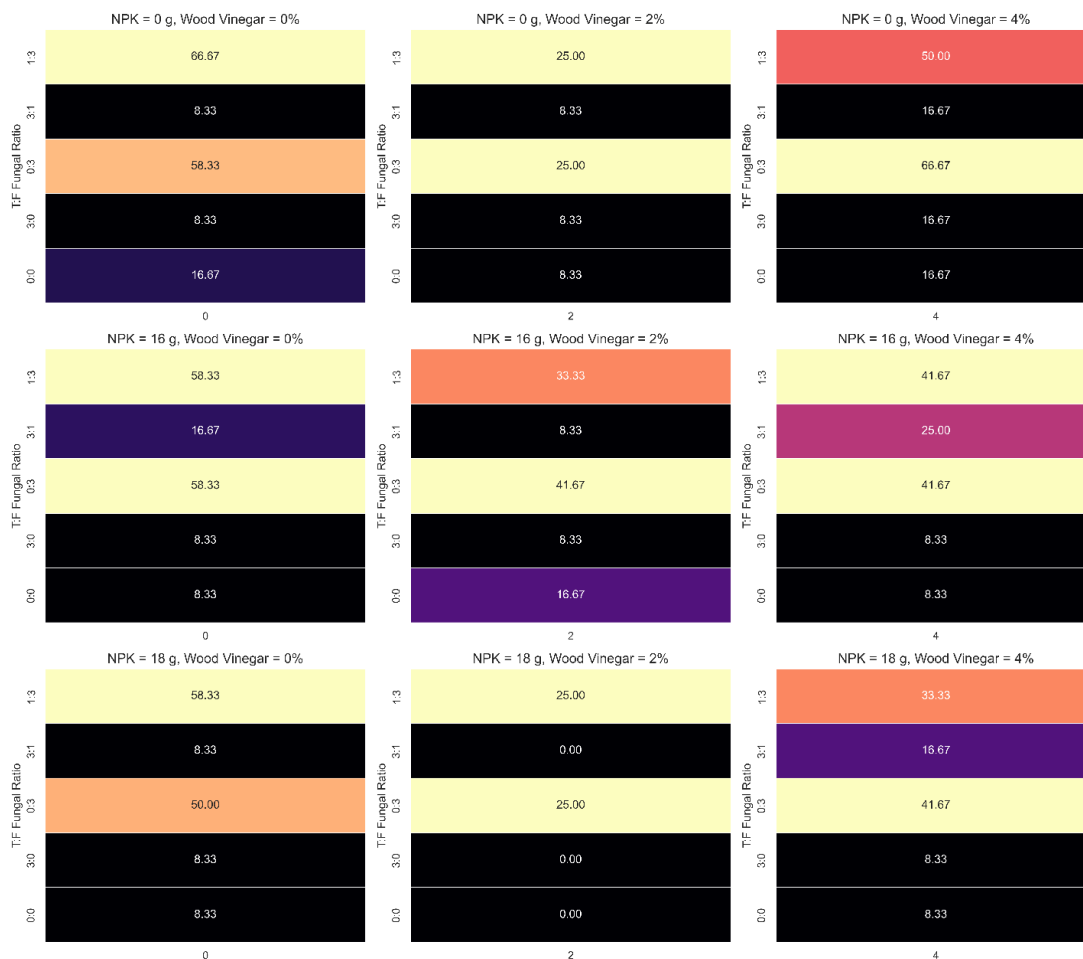
Each value represents the mean of three replicates.

LSD<sub>0.05</sub> = 1.897 (fertilizer), 3.285 (fertilizer × vinegar), 7.345 (three-way interaction), 4.241 (vinegar × fungi), 2.448 (fungal rate).

**Figure (1)** Effect of organic NPK fertilizer, wood vinegar and fungal ratios on tomato seed germination (%).

The results of the interaction of organic NPK fertilizer, wood vinegar concentrations and mixing ratios between fungi showed that the highest percentage of seed germination appeared in the treatment of 18 gm fertilizer and 2% wood vinegar concentration T:F (0:0), the treatment of 18

gm fertilizer and 2% wood vinegar concentration and T:F (3:0), and the treatment of 18 gm fertilizer and 2% wood vinegar concentration and T:F (3:1), where the percentage reached 100.00% for each treatment, with significant differences from the rest of the treatments. The results of the effect of organic NPK fertilizer and mixing ratios between fungi showed that the highest percentage of seed germination appeared in the treatment of 18 gm fertilizer and T:F (0:0) and the treatment of 18 gm and T:F (3:0), where the percentage reached 94.44% for both treatments, with significant differences from the rest of the treatments except for the treatment of 18 g fertilizer and T:F (3:1) and the treatment of 16 gm fertilizer and T:F (3:0). The results of the effect of wood vinegar concentrations showed that the highest percentage of seed germination was at a concentration of 2%, reaching 84.44%, with significant differences from the rest of the treatments. The results of the interaction of wood vinegar concentrations and mixing ratios between fungi indicated that the highest percentage of seed germination was at a concentration of 2% wood vinegar and T:F (3:0), and the treatment of 2% wood vinegar and T:F (3:1), reaching 94.44%, with significant differences from the rest of the treatments except for 2% wood vinegar and T:F (0:0), and the treatment of 2% wood vinegar and T:F (3:0).

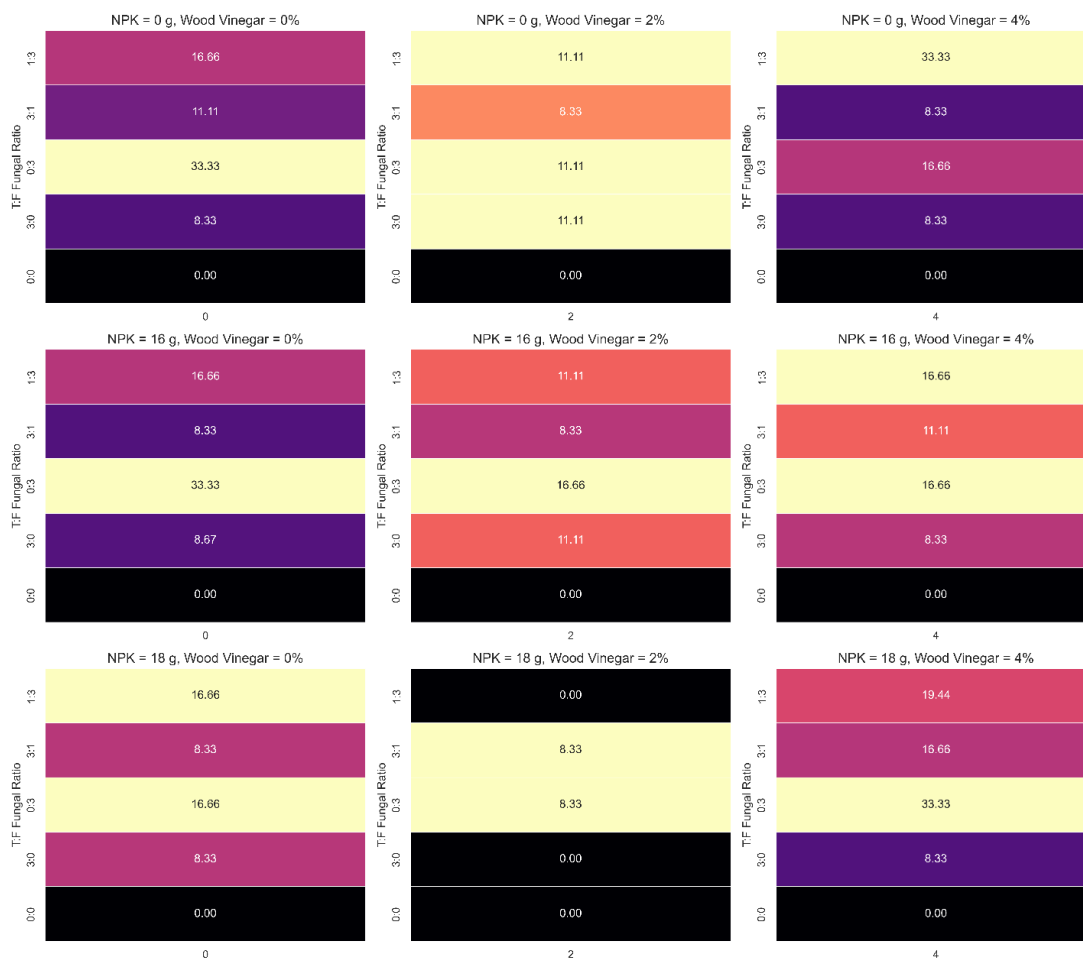


Each number in the figure represents the average of three replicates\*=  
 F= *Fusarium solani*      T= *Trichoderma hamatum*

**Figure (2)** Effect of organic NPK fertilizer, wood vinegar and Fungal Ratios on tomato seed rot (%).

The results of the effect of mixing ratios between fungi showed that the highest percentage of seed germination appeared in the T: F (3:0) treatment and the T: F (0:0) treatment, reaching 91.66% and 89.81% respectively.

The results of Figure (2) indicated that the lowest percentage of tomato seed rot in the organic NPK fertilizer treatment appeared in the 18 g treatment, where the percentage reached 19.45%, with significant differences from the rest of the treatments. The results of the effect of organic NPK fertilizer and wood vinegar concentrations showed that the lowest percentage of seed rot was in the treatment of 18 gm fertilizer and 2% wood vinegar concentration, where the percentage reached 10.00% with significant differences from the rest of the treatments. The results of the interaction of organic NPK fertilizer, wood vinegar concentrations, and mixing ratios between fungi showed that the highest percentage of seed rot was in the treatment of 0 gm fertilizer and 0% wood vinegar concentration and T: F (1:3), and in the treatment of 0 gm fertilizer and 4% wood vinegar concentration and T: F (3:0), where the percentage reached 66.67% for both treatments, with significant differences from the rest of the treatments. The results of the effect of organic NPK fertilizer and mixing ratios between fungi showed that the highest percentage of seed rot was in the treatment of 0 mg mfertilizer and T: F (3:0) where the percentage reached 50.00% and significant differences from the rest of the treatments except for the treatment of 16 gm fertilizer and T:F (0:3) and the treatment of 0 gm fertilizer and T:F (1:3).



Each number in the figure represents the average of three replicates\* =

F= *Fusarium solani*      T= *Trichoderma hamatum*

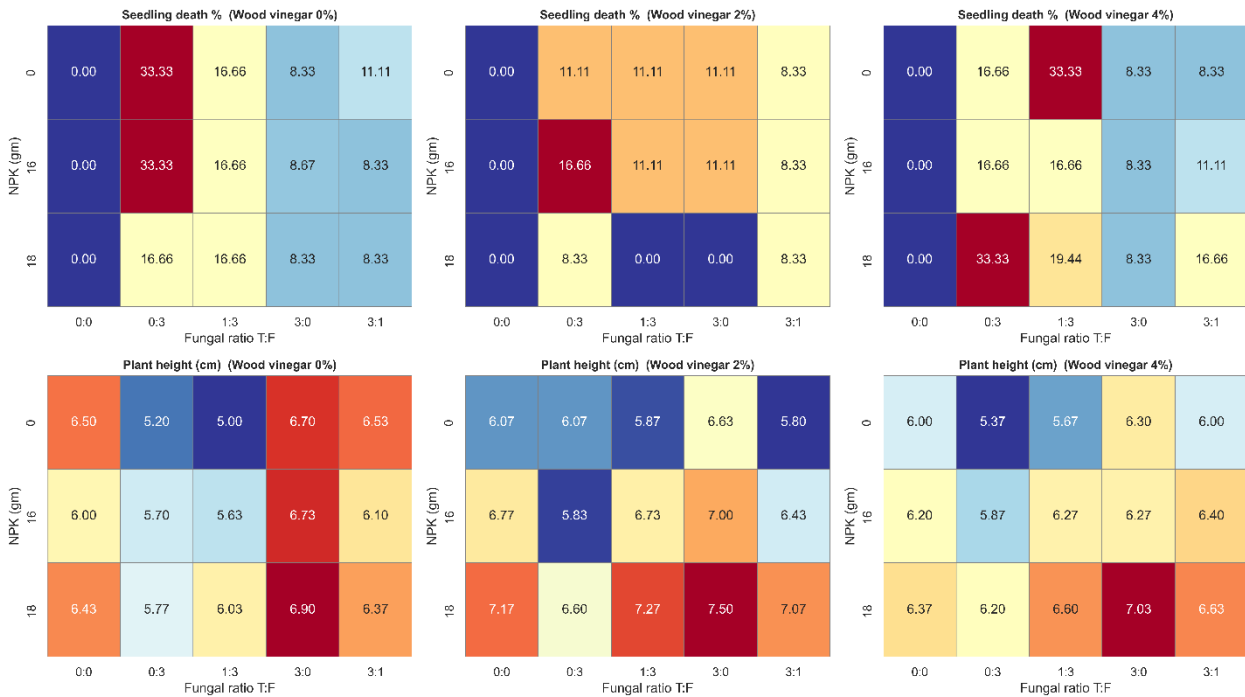
**Figure (3)** The effect of organic NPK fertilizer and wood vinegar and Fungal Ratios on tomato seed seeding death (%).

The results of the effect of wood vinegar concentrations showed that the lowest percentage of seed rot was at a concentration of 2% where the percentage reached 15.56% and significant differences from the rest of the treatments. The results of the interaction of wood vinegar concentrations and mixing ratios between fungi showed that the highest percentage of seed rot was at a concentration of 0% and T: F (0:3) where the percentage reached 55.56% and significant differences from the rest of the treatments. The results of the effect of mixing ratios between fungi on tomato seeds showed that the lowest percentage of seed rot was in the T:F (3:0) treatment, where the percentage reached 8.33%, with significant differences from the rest of the treatments except for the T: F (0:0) treatment.

The results of Figure (3) showed that the lowest percentage of tomato seedling death in the organic NPK fertilizer treatment was in the 18-gm treatment, where the percentage reached 9.630%, with significant differences from the rest of the treatments. The results of organic NPK fertilizer and wood vinegar concentrations proved that the lowest percentage of seedling death was in the 18-gm treatment and 2% wood vinegar concentration, where the percentage reached 3.333%, with significant differences from the rest of the treatments. The results of the interaction of organic NPK fertilizer, wood vinegar concentrations and mixing ratios between fungi showed that the highest percentage of seedling death was in the treatment of 0 gm fertilizer and 0% wood vinegar concentration and T:F (0:3), neglected 16 gm fertilizer and 0% wood vinegar concentration and T:F (0:3), treated 18 gm fertilizer and 4% wood vinegar concentration and T:F (0:3), and treated 0 gm fertilizer and 4% wood vinegar concentration and T:F (1:3), where the percentage reached 33.33% for each treatment, with significant differences from the rest of the treatments. The results of the effect of organic NPK fertilizer and mixing ratios between fungi showed that the highest percentage of seedling death appeared in the treatment of 16gm and T: F (0:3), where the percentage reached 22.22%, with significant differences from the rest of the treatments. The results of the effect of wood vinegar concentrations indicated that the lowest percentage of seedling death appeared at a concentration of 2%, reaching 7.037%, with significant differences from the rest of the treatments. The results of the interaction of wood vinegar concentrations and mixing ratios between fungi showed that the highest percentage of seedling death appeared at a concentration of 0% wood vinegar and T: F (0:3) reaching 27.77%, with significant differences from the rest of the treatments. The results of the effect of mixing ratios between fungi showed that the lowest percentage of seedling death was in the T: F (0:0) treatment, reaching 00.00%, with significant differences from the rest of the treatments.

The results of Figure (4) showed that the highest height of tomato seedlings in the organic NPK fertilizer treatment was in the 18gm treatment, where it reached 6.662 cm, with significant differences from the rest of the treatments. The results of the effect of organic NPK fertilizer and wood vinegar concentrations indicated that the highest height was in the 18gm treatment and 2% wood vinegar concentration, where it reached 7.12 cm, with significant differences from the rest of the treatments. The results of the interaction of organic NPK fertilizer, wood vinegar concentrations and mixing ratios between fungi showed that the highest height appeared in the treatment of 18 gm fertilizer, 2% wood vinegar concentration and T:F (3:0) where it reached 7.50 cm with significant differences from the rest of the treatments except for the treatment of 18 gm fertilizer, 2% wood vinegar concentration and T:F (0:0), the treatment of 18 (g) fertilizer, 2% wood vinegar concentration and T:F (3:1), and the treatment of 18 gm fertilizer, 2% wood vinegar concentration and T:F (1:3). The results of the effect of organic NPK fertilizer and mixing ratios between fungi proved that the highest height was in the treatment of 18 gm fertilizer and T: F (3:0) where it reached 7.0144 cm with significant differences from the rest of the

treatments. The results of the effect of wood vinegar concentrations showed that the highest increase appeared in the 2% wood vinegar concentration, reaching 6.587 cm, with significant differences from the rest of the treatments. The results of the interaction of wood vinegar concentrations and mixing ratios between fungi showed that the highest increase appeared in the 2% wood vinegar concentration and T: F (3:0), reaching 7.044 cm, with significant differences from the rest of the treatments. The results of the effect of mixing ratios between fungi indicated that the highest increase appeared in the T: F (3:0) treatment, reaching 6.785 cm, with significant differences from the rest of the treatments.



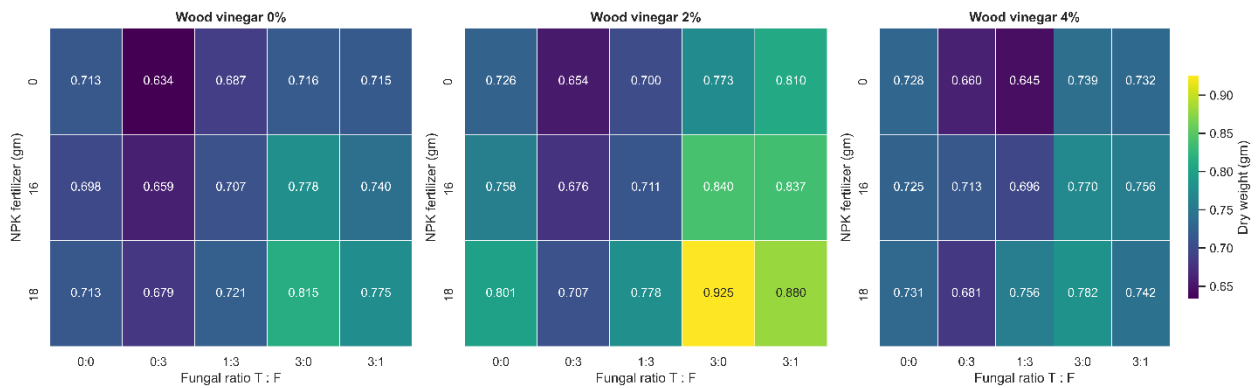
Each number in the figure represents the average of three replicates\*=-

F= *Fusarium solani* T= *Trichoderma hamatum*

**Figure (4)** Effect of organic NPK fertilizer and wood vinegar and mixing ratios between *F.solani* and *T.hamatum* on the height of tomato plants in pots (cm).

The results of Figure (5) showed that the highest dry weight of the vegetative group of tomato seedlings in the organic NPK fertilizer treatment was in the 18 (g) treatment, where the dry weight reached 0.7657 g, with significant differences from the rest of the treatments. The results of the effect of organic NPK fertilizer, wood vinegar concentrations, and mixing ratios between fungi indicated that the highest dry weight was in the treatment of 18 (g) fertilizer and 2% wood vinegar concentration, where the weight reached 0.8181 g, with significant differences from the rest of the treatments. The results of the interaction of organic NPK fertilizer, wood vinegar concentrations, and mixing ratios between fungi showed that the highest dry weight appeared in the treatment of 18 (g) fertilizer and 2% wood vinegar concentration and T:F (0:3), where the weight reached 0.9250 g, with significant differences from the rest of the treatments except for the treatment of 18 (g) fertilizer and 2% wood vinegar concentration and T:F (1:3). The results of the effect of organic NPK fertilizer and mixing ratios between fungi showed that the highest dry weight was in the treatment of 18 (g) fertilizer and T:F (0:3) where it reached 0.8407 g with significant differences from the rest of the treatments. The results of the effect of wood vinegar concentrations showed that the highest dry weight appeared in the 2% concentration where it reached 0.7717 g with significant differences from the rest of the concentrations. The results of

the interaction of wood vinegar concentrations and mixing ratios between fungi indicated that the highest dry weight was observed in the 2% concentration and T: F (0:3) where it reached 0.8460 g with significant differences from the rest of the treatments except for the 2% wood vinegar and T: F (1:3) treatment. The results of the effect of mixing ratios between fungi proved that the highest dry weight appeared in the T: F (0:3) treatment where it reached 0.7432 g with significant differences from the rest of the treatments except for the T: F (1:3) treatment.

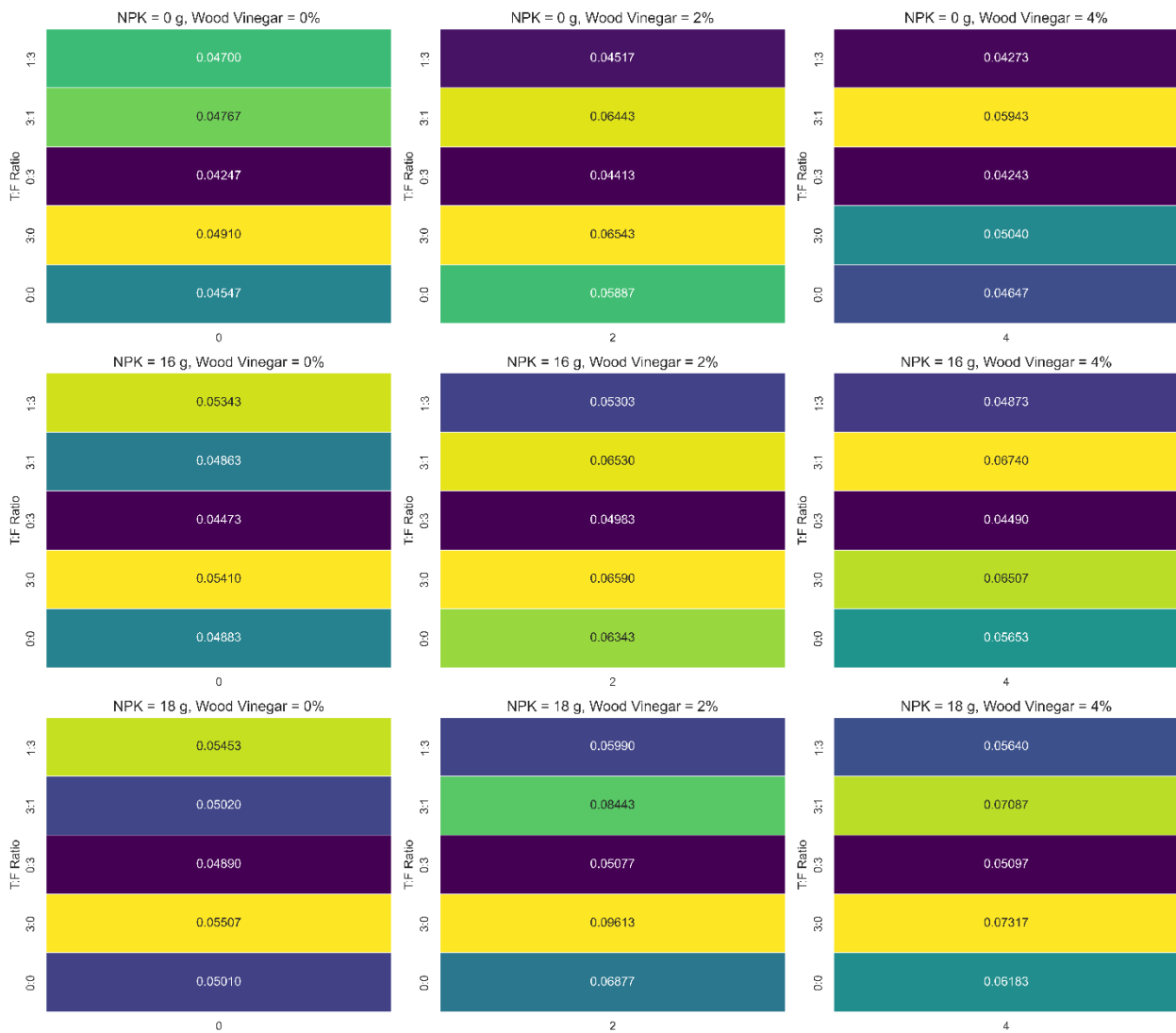


Each number in the figure represents the average of three replicates\*=  
 F= *Fusarium solani*      T= *Trichoderma hamatum*

**Figure (5)** The effect of organic NPK fertilizer and wood vinegar and mixing ratios between *F.solani* and *T.hamatum* fungi on the dry weight of the vegetative group of tomato seedlings in pots Weight (gm)

The results of figure (6) indicated that the highest dry weight of the root system of tomato seedlings in the organic NPK fertilizer treatment appeared in the 18gm treatment, where the weight reached 0.06214 gm with significant differences from the rest of the treatments. The results of the effect of organic NPK fertilizer and wood vinegar concentrations showed that the highest dry weight was in the 18gm treatment and 2% wood vinegar concentration, where the weight reached 0.07200 gm with significant differences from the rest of the treatments. The results of the interaction of organic NPK fertilizer, wood vinegar concentrations, and mixing ratios between fungi proved that the highest dry weight appeared in the 18gm treatment and 2% wood vinegar concentration T: F (0:3), where the weight reached 0.09613 gm with significant differences from the rest of the treatments. The results of the effect of organic NPK fertilizer and mixing ratios between fungi showed that the highest dry weight was in the 18gm treatment and T: F (0:3) where the weight reached 0.07479 gm with significant differences from the rest of the treatments. The results of the effect of wood vinegar concentrations proved that the highest dry weight appeared in the 2% concentration where the weight reached 0.06237 gm with significant differences from the rest of the treatments. The results of the interaction of wood vinegar concentrations and mixing ratios between fungi showed that the highest dry weight appeared in the 2% wood vinegar concentration and T: F (0:3) where the weight reached 0.07582 gm with significant differences from the rest of the treatments. The results of the effect of mixing ratios between fungi proved that the highest dry weight was in the T: F (0:3) treatment where the weight reached 0.06382 gm with significant differences from the rest of the treatments.

The decreased growth parameters in plants may be attributed to the ability of the fungal hyphae of the pathogenic fungus *F. solani* to induce cellular changes such as cytoplasmic dissolution, organelle destruction, and cell wall disintegration (Huang et al., 2016; El-Kazzaz et al., 2022).



Each number in the figure represents the average of three replicates\*=  
 F= *Fusarium solani*      T= *Trichoderma hamatum*

**Figure (6)** Effect of organic NPK fertilizer and wood vinegar and mixing ratios between *F.solani* and *T.hamatum* fungi on the dry weight of the root system of tomato seedlings in pots weight (gm).

Alternatively, the reason may be due to the ability of *F. solani* to secrete numerous enzymes and toxins such as pectinases, cellulases, ligninases, and fusaric acid, which give the fungus its pathogenic potential and affect seed germination and seedling growth (Martinez et al., 2025; Torres et al., 2025). *F. solani* has a strong impact on growth traits such as stem length, root length, and fresh and dry weight, as its function relies primarily on cell wall-degrading enzymes, the most important of which is polygalacteronase, which primarily degrades the midrib, causing soft rot of the embryonic stem and root hairs (Al-Khero and Al-Obaidy, 2020). The increase in growth indicators such as germination percentage and fresh and dry weight of the vegetative and root system using the *Trichoderma* spp. biofactor or treatments inoculated with the pathogenic fungus in the presence of the biofactor is due to the fact that the biofactor produces secondary receptors such as Gibberelins, Siderophores and Indole-3-acetic acid in the soil surrounding the roots. These substances can contribute to enhancing plant growth while reducing disease incidence (Alanzi et al., 2024). These secondary receptors have roles within the plant in addition to their role in enhancing root growth (Castro-Camba et al., 2022). The production of Siderophores by the biofactor is not limited to removing iron from the pathogenic fungus only,

but it has an auxiliary role as it provides the plant with iron that helps enhance plant growth and improve health (Ghosh et al., 2017; AbdEl-Hamid et al., 2025). Or perhaps the reason is due to the various mechanisms of the fungus, including parasitism and direct competition, especially in the root zone, in addition to the production of antibiotics and enzymes that have a direct effect in killing or inhibiting competing organisms, in addition to its ability to stimulate plant growth by stimulating systemic defense responses against Biotic and abiotic stresses and plant activation in response to future stresses (Woo et al., 2023). In addition, it possesses various strategies for resisting fungal pathogens (Lyubenova et al., 2023). Previous studies have shown that the use of some *Trichoderma* spp. fungi, such as *Trichoderma asperellum*, is effective in inhibiting the growth of plant pathogenic fungi such as *F. oxysporum*, *F. solani*, *Alternaria alternata*, *R. solani*, and *F. graminearum*, in addition to stimulating tomato seed germination and enhancing plant growth (Sehim et al., 2023).

As for organic fertilizer, its effect may be attributed to the release of phenolic compounds and short-chain organic acids during the fermentation process, such as acetic acid, butyric acid, propanoic acid, and antibiotic-like compounds. These compounds inhibit the germination of fungal spores (Bonanomi et al., 2023). Or perhaps the reason is due to organic fertilizers, especially poultry manure and cow manure, which when decomposed produce humic acids that can disrupt the functions of the fungal cell membrane and inhibit enzymes necessary for plant invasion. These acids may also interfere with the chemical signals of the fungus *F. solani* (Canellas and Olivers, 2024). As for the effect of wood vinegar, the reason may be attributed to the vinegar containing organic acids such as acetic acid, formic acid, and propionic acid. These acids work to reduce the alkalinity of the soil and thus improve the solubility of elements such as phosphorus, iron, and zinc, which helps improve soil fertility and microbial activity. In addition, these acids play a role in dissolving minerals and improving the permeability of root membranes, which increases the efficiency of nutrient absorption (Muflihah et al., 2022). Or perhaps the reason is due to the effectiveness of organic acids in destroying the cell membranes of the pathogenic fungus or inhibiting its enzymes (Saputra et al., 2021).

#### 4. Conclusions

This work provides evidence that *Fusarium solani* is devastating for tomato seed germination and seedling growth. The effect of the pathogenic fungus *Fusarium solani* was evident, as it was highly pathogenic to tomato seedling germination and growth, causing a significant reduction in seed germination rates.

A 2% WV, concentration of wood vinegar and (18 g/kg of pot) of NPK fertilizer outperformed the other treatments, resulting in the highest tomato seed germination rates, the highest seedling height, and the highest dry weight of both shoots and roots. The presence of the biocontrol agent *Trichoderma hamatum* helped to reduce the impact of the disease. Combined application of these treatments provides a potent and environment-friendly approach to control with tomato damping-off.

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