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Effect of plant extracts on important fungal pathogens and germination of tomato seed

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Abstract

The objective of this study was to evaluate the antifungal activity of ethanolic extracts of seven spices against selected soil and seed-borne fungal pathogens that affect tomato as well as the effect of their concentrations on the germination of tomato seed. Bioactive compounds from clove, cinnamon, black pepper, turmeric, ginger, cardamom and lemongrass were extracted in ethanol, concentrated under vacuum and tested for antifungal activity against *Pythium, Alternaria solani* and *Fusarium oxysporum* f. sp *lycopersici* in a poisoned food experiment. Four concentrations of 10, 20, 30 and 40% were made from the plant extracts and untreated tomato seeds were soaked in each for 12 hours and then incubated in moist blotter chambers and germination monitored over 20 days. Results indicated that clove, turmeric, ginger and black pepper were active in inhibiting the growth of all the pathogens by about 81%. *Pythium* was the most susceptible pathogen and its growth was completely inhibited by ginger, clove, black pepper extracts as well as the fungicide. High germination percentages of up to 99% were recorded in seeds treated with lemongrass, black pepper, cardamom, turmeric and cinnamon diluted by 30 and 40%. This study confirms the effectiveness of plant extracts as antifungal agents that also support the germination of seeds at the appropriate concentrations and should be considered for the development of a botanical seed treatment. Clove, black pepper and ginger should be considered as sources for botanical pesticides for the management of damping-off in tomato seedbeds.

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Introduction

In spite of the effort taken by governments and private companies to ensure the existence of a formal seed system, some farmers still rely on informal seed sources every planting season (Muthoni and Nyamongo, 2008). Traditionally, farmers would select the best seed from their harvest and preserve them for planting in the following season and the quality of that seed was as determined by the farmer. According to Njonjo *et al.* (2019), farmer saved cowpea seeds proved to meet the standard germination percentages but were physically impure and had low growth vigor. Once such seeds are planted, they translate into an unhealthy plant stand and eventually low yields and of reduced quality. Certified seeds are available in many agricultural inputs' shops but some tomato farmers still opt to use seeds from harvested, and not very healthy tomato fruits, dry and prepare them for the next planting season (Mtui *et al.*, 2010; Bortey *et al.*, 2011). Since the use of farmer saved seed practice has been there for a long time, it has actually been recognized as a seed system (Munyi and Jonge, 2015). Other than low yield, another disadvantage of farmer saved seed is the presence of a wide range of seed-borne pathogens. Many studies have reported a myriad of seed-borne fungal and bacterial pathogens in various crop seeds (Somda *et al.*, 2007; Wolf *et al.*, 2008; Mbega *et al.*, 2012; Dauda *et al.*, 2017). Soil and seed-borne pathogens affecting tomato include species of *Fusarium, Alternaria, Rhizoctonia, Verticillium, Chlamydosporium, Aspergillus, Penicillium, Botrytis, Chaetomium* among others (Chohan *et al.*, 2017; Ghinaiya and Pandya, 2017; Kadoglidou *et al.*, 2020).

The only solution to attaining higher yield while using farmer saved seed is to treat the seed against soil and seed-borne pathogens. Many farmers rely on chemicals to treat their seed and the effectiveness of such chemicals is undoubtedly guaranteed and is the most common practice (Signaboubo *et al.*, 2015). In a study conducted by Buyela *et al.* (2018), all the chemical fungicides tested on wheat seeds showed a germination range of between 48-98% and a relatively reduced seed infection. The fungicides are quite efficacious and result in a healthy plant stand and an appreciable yield. The chemicals however contribute to environmental pollution, are a health hazard and interferes with biodiversity (Findura *et al.*, 2020).

The cost of certified and or treated seed is sometimes high for an average smallholder farmer to acquire (Muthoni and Nyamongo, 2008). It is however noteworthy that seed treatment is vital for a healthy plant stand which translates to a decent yield (Joshi *et al.*, 2016) and that chemicals are not the only strategies for seed treatment. Explorations continue to be made on the usage and effectiveness of plant extracts in seed dressing (Gyasi *et al.*, 2020). Interestingly, plant extracts have majorly been researched for their antimicrobial effects and possible applications as plant protection products (Nwachukwu and Umechuruba, 2001; Alam *et al.*, 2014; Shabana *et al.*, 2017). Even as seed treatments, the focus of many studies is still on the antimicrobial potential of botanical preparations. This is because of the importance associated with seed-borne pathogens and their effect on crop quality and yield. Botanical preparations have been used as seed treatments on several crops such as tomato (Mbega *et al.*, 2012), wheat (Mahal and Akter, 2019), sorghum (Masum *et al.*,2009), cabbage (Wolf *et al.*, 2008), pea (Chandel and Kumar, 2017), cauliflower (Findura *et al.*, 2020), cotton, barley (Ahmad *et al.*, 2016) and cowpea (Akinbude and Ikotun, 2008).

It is significant to say that other studies have focused on different aspects of plant extracts as seed treatments. Findura *et al.* (2020) explored the allelopathy aspect of plant extracts on germination of cauliflower seed as well as the most effective method of treating the seeds. In addition, their study also focused on appropriate methods of extraction in order to maximize the yield of plant bioactive compounds. El-Dahab *et al.* (2016) explored the applicability of plant extracts as treatment for stored sorghum seed and the resultant effect on seed viability. The overall effect of plant extracts as seed dressers and the spillover effect on plant development has also been reported (Shabana *et al*., 2017). Examples of plants used as seed dressers include garlic, ginger, black pepper, lemongrass, moringa, neem, clove, garden quinine, cumin, cedar, onions, bel leaf, turmeric, cinnamon *inter alia*. Selected studies have also reported that despite the remarkable effect of plant extracts in a seed dressing, some plants have toxic effects on the seeds and may interfere with germination and overall seed transition into seedlings. This is because of the presence of secondary metabolites which, at varying concentrations, may either stimulate, slow, or hinder germination of seed (Siddiqui, 2007; Pan *et al*., 2008; Wolf *et al*., 2008).

There is a need to further explore the toxicity of these botanical preparations on seed germination. This study focused on the effect of seven ethanolic spice extracts against three soil and seed-borne pathogens of tomato, *Alternaria solani*, *Fusarium oxsoporum* f. sp *lycopersici* and *Pythium*. The study also evaluated the effect of four different concentrations of the seven extracts on the germination of tomato seeds.

The plants considered for this study have all been reported to have antifungal activity on a wide range of fungal plant pathogens and especially of tomato.

Materials and methods

Preparation of ethanolic spice extracts

The plant extracts were prepared following modified procedures adopted from Rizwana (2016). Seven spice plants *viz* turmeric (*Curcuma longa*), cardamom (*Elletaria cardamomum*), cinnamon (*Cinnamomum* spp), lemongrass (*Cymbopogon citratus*), ginger (*Zingiber officinale*), clove (*Syzygium aromaticum*) and black pepper (*Piper nigrum*), in powder form were purchased in Soko Kuu market in Tanga, Tanzania. The powders were separately soaked in ethanol at the ratio of 1:1.5 (w/v) for one week with constant shaking. The mixture was filtered through dual layers of cheese cloth followed by Whatman No. 1 filter paper. The alcohol in the filtrate was evaporated under vacuum at 40°C.

Bioassay of the ethanolic spice extracts for antifungal activity

The ethanolic spice extracts were evaluated for antifungal activity by culturing the test fungi on potato dextrose agar (PDA) medium amended with the extracts following modified procedures by Muthomi *et al.* (2017). The test fungal pathogens were *Pythium spp., Alternaria solani* and *Fusarium oxysporum* f. sp. *lycopersici* which cause damping-off of seedlings, early blight and wilt of tomato, respectively. The stock solution of each spice extract was prepared at a concentration of 1g $ml^{-1}$and 100µl of extract drawn and mixed with 900 µl of ethanol. Half a milliliter of the solution was incorporated into fifteen milliliters of molten potato dextrose agar media at 45°C to allow evaporation of ethanol. Plates containing media amended with Ridomil Gold® (metalaxyl-M 40g/kg and mancozeb 640g/Kg), a fungicide used for management of fungal diseases in tomato, were used as a positive check while negative control plates consisted of PDA media without any amendment. Three-millimeter agar plugs were cut from pure cultures of each of the three fungal pathogens and placed at the center of the PDA agar plates and incubated at room temperature for up to 8 days. The experiment was laid out in a completely randomized design in triplicate. Antifungal activity of the extracts against the fungal pathogens was determined by measuring the colony radial growth of the fungi cultured on media amended with extracts compared to that of fungi cultured on unamended media. The colony radial growth was measured every two days until the 8th day after plating. Percentage inhibition of the fungal colony diameter was calculated using the following formula:

$$\% \text{ Inhibition} = \frac{\text{Colony diameter (Control)} \quad \text{Colony diameter (Treatment)}}{\text{Colony diameter (Control)}} \times 1$$

Evaluation of the effect of ethanolic spice extracts on seed germination

Untreated seeds of tomato variety, Money Maker®, were obtained from a local farm nursery that supplies tomato farmers with seedlings established from seeds extracted from ripened tomato fruits. The effect of spice extracts on tomato seed germination was determined following modified procedures by Islam and Kato-Noguchi (2014). The ethanolic spice extracts were subjected to a ten-dilution where one millilitre of each stock extract was diluted in nine millilitres of sterile distilled water. Four concentrations of 10, 20, 30 and 40% were further derived from the first, second, third and fourth dilution respectively. Tomato seeds were surface sterilized in 2% sodium hypochlorite for two minutes, rinsed in three changes of sterile distilled water and soaked overnight in each of spice extract concentrations. Seeds soaked in Ridomil Gold® (metalaxyl-M 40g/kg and mancozeb 640g/Kg) were used as a positive check and seeds soaked in sterile distilled water as the negative control. The experiment was laid out in a completely randomized design in triplicate and repeated once. After 12 hours of soaking, 25 seeds were placed in incubation chambers lined with four layers of moistened blotter paper and incubated at a temperature range of 25 – 27°C (ISTA, 2015). The number of germinated seeds was counted after every three days starting at the 7th day until the 20th day of incubation. Germination was considered to have occurred if the radicle had protruded at least two millimetres from the seedcoat.

Data analysis

Analysis of variance was used to compare the effects of plant extracts on the growth of soil and seed-borne pathogens and how different concentrations of the extracts influenced the germination of tomato seed. Means were separated by Tukey's test at 5%. The software used for analysis was Genstat® 15th Edition, VSN International.

Results

Antifungal activity of spice extracts against soil-borne pathogens

All the tested plant extracts were significantly ($P \leq 0.05$) effective in inhibiting the growth of all the tested fungal pathogens of tomato (Table 1).

Table 1. Percentage inhibition of colony radial growth of soilborne fungal pathogens of tomato cultured on PDA amended with plant extracts at 8 days after incubation.

Extracts	*Alternaria*		*Fusarium*		*Pythium*		Mean	
Clove	73.3	a	70.6	a	100.0	a	81.3	a
Turmeric	60.0	ab	74.2	a	98.2	a	77.5	ab
Black pepper	62.5	ab	69.6	ab	100.0	a	77.4	ab
Ginger	53.8	b	62.7	b	100.0	a	72.2	ab
Ridomil®	64.1	ab	48.0	c	100.0	a	70.7	b
Cardamom	52.9	b	54.1	c	67.0	b	58.0	c
Cinnamon	30.6	c	48.5	c	66.5	b	48.5	d
Lemongrass	36.4	c	54.4	c	38.8	c	43.2	d
s.e.m	3.1		1.5		5.1		3.5	
s.e.d	4.4		2.1		7.2		5.0	
L.S. D (5%)	8.9		4.3		14.8		9.9	
CV (%)	11.2		4.8		12.1		10.8	

Means followed by the same letter(s) within each column do not differ significantly at $P \leq 0.05$.

Extracts of clove inhibited the growth of all the pathogens by about 81%. The activity of clove was closely followed by turmeric, ginger and black pepper and their activity had no significant ($P \leq 0.05$) difference with that of the commercial fungicide, Ridomil Gold, containing metalaxyl and mancozeb. Antifungal activity of lemongrass was the least among all the extracts and compared to the positive control. The difference in susceptibility of the pathogens to the extracts was also significant ($P \leq 0.05$). Among the pathogens, *Pythium* was the most susceptible followed by *Alternaria solani* (Fig. 1). Pythium was completely inhibited by extracts of clove, black pepper, ginger and the commercial fungicide and up to 98% by turmeric. The growth of *Alternaria solani* was inhibited by clove to about 73%, an activity that was about 14% higher than that of the commercial fungicide. There were no significant ($P \leq 0.05$) differences in the susceptibility of *Alternaria* among all extracts except for cinnamon and lemongrass whose inhibition activity ranged between 30 – 36%. *Fusarium oxysporum* f. sp. *lycopersici* was the least susceptible pathogen (Fig. 1) and its growth was best inhibited by turmeric, clove, black pepper and ginger in that order. The activity of the four extracts against the wilt pathogen had no significant ($P \leq 0.05$) difference. The antifungal activity of the commercial fungicide against *Fusarium* was below 50% (Table 1).

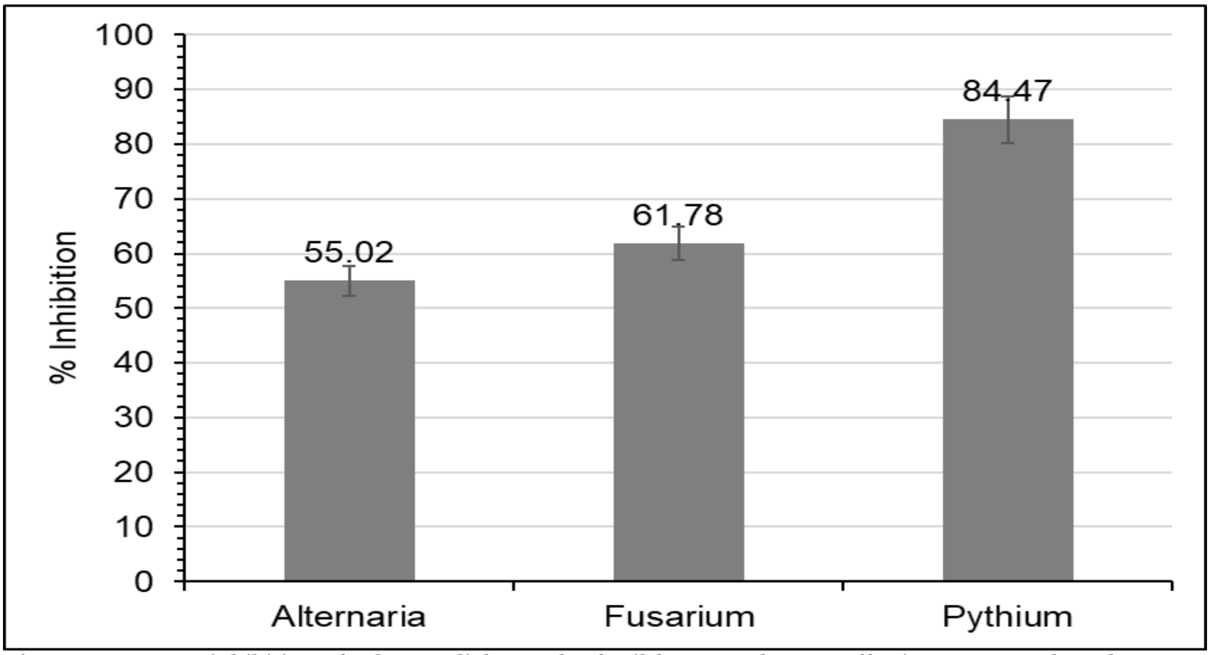

Fig. 1. Percentage inhibition of colony radial growth of soil-borne pathogens affecting tomato cultured on PDA media amended with ethanolic spice extracts at 8 days after incubation.

Effect of different concentrations of ethanolic plant extracts on germination of tomato seed

All the tested plant extracts significantly ($P \leq 0.05$) influenced the germination of tomato seed on different days after incubation. There were also significant differences in the effect of seed germination among the four concentrations. At 10 days after incubation, the effect of extracts at the concentration of 10% varied significantly. The highest germination was recorded in seeds treated with water (73%) followed by lemongrass extracts at 31%. All the other extracts registered germination of below 15%. As of 10 days after incubation, ginger registered zero germination (Fig. 2). The effect of the 10% on 20 days after incubation showed a similar trend with the highest germination still registered in seeds treated with water (88%). There was a high germination rate in seeds treated with lemongrass at 75%, cinnamon, black pepper and cardamom registered a germination percent of between 50-60% while the rest remained below 50%. At 10% concentration, ginger extracts registered the least germination percentage of about 11% (Fig. 2). No extract supported germination of about 50% at 10% concentration within the first 10 days of incubation.

The effect of the 20% concentration at different days after incubation was also significantly different. At 10 days after incubation, black pepper and cinnamon extracts registered a germination percent of about 83% while turmeric and water registered above 73%. The commercial fungicide, cardamom and clove extracts registered germination of 56-60%. Ginger extracts only supported germination of 21%. (Fig. 3).

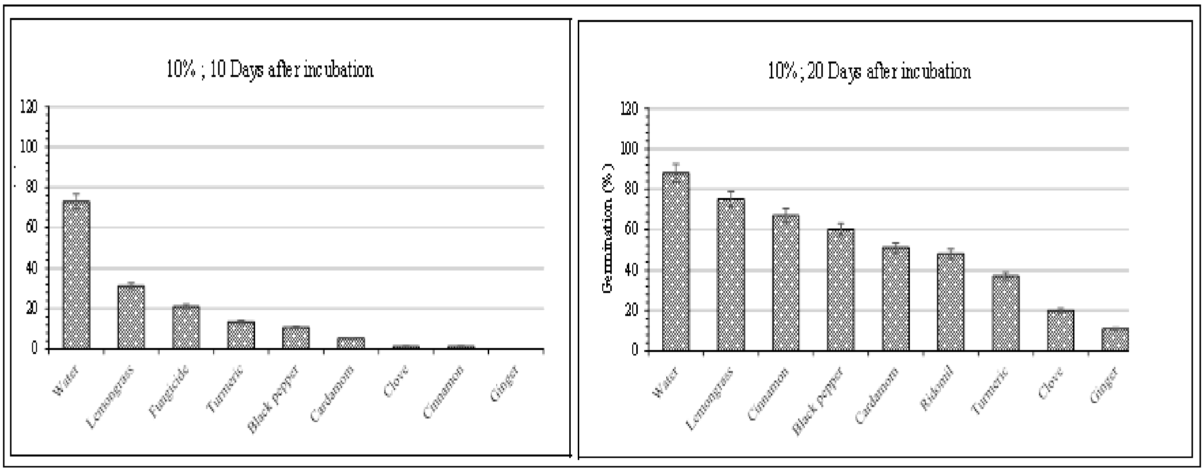

Fig. 2. Germination percentage of tomato seeds treated with 10% concentration of plant extracts at 10 and 20 days after incubation.

At a concentration of 20% on 20 days after incubation, cinnamon, lemongrass and turmeric supported germination of above 90%, clove, water, cardamom and the fungicide above 80% and ginger up to 65% (Fig. 3). The extracts that supported high germination of between 60-83% at a concentration of 20% within the first 10 days of incubation were from black pepper, cinnamon, turmeric, lemongrass and clove.

At a concentration of 30% on 10 days after incubation, the highest germination of above 90% was registered in seeds treated with black pepper extracts. Extracts of turmeric, lemongrass and clove supported germination of about 80%, cinnamon extracts and water about 70%, cardamom and fungicide between 64-68% while ginger extracts supported germination of about 56% (Fig. 4). A similar trend was observed 20 days after incubation with black pepper, turmeric, clove and lemongrass extracts supporting germination of above 90%. The fungicide, cardamom, water and ginger extracts supported germination of between 81-89%. Extracts of black pepper, turmeric, lemongrass and clove supported higher germination than the positive and negative control treatments (Fig. 4). At a concentration of 30%, the extracts that supported high germination of tomato seeds of between 73-91% within 10 days after incubation were from black pepper, turmeric, lemongrass, clove and cinnamon. 10 days after incubation at a concentration of 40%, cinnamon extracts supported a germination percentage of above 90%. Black pepper, lemongrass and cardamom supported germination of between 83-89% while clove, turmeric and ginger extracts supported 75% germination of tomato seed. The positive and negative control was the least supporting germination of 65% and 73% respectively (Fig. 5). At 20 days after incubation, cinnamon extracts supported a germination percentage of 99%. Extracts of black pepper, lemongrass, clove, cardamon and the fungicide supported germination of between 91-93% while turmeric, ginger and the negative control supported germination of between 81-88% (Fig. 5). At a concentration of 40%, all the extracts supported high germination of between 75-99% within the first 10 days of incubation.

Discussion

The plant extracts tested for antifungal activity against soilborne pathogens showed significant activity with clove, turmeric, black pepper and ginger being the most active compared to the positive control. Antifungal activity of clove against *Alternaria, Fusarium* and *Pythium* has been previously reported by studies focusing on tomato as well as other crops (Kareem *et al.*, 2009; Shukla and Dwivedi, 2012; McMaster *et al.*, 2013; Castro *et al.*, 2017; Yerukala *et al.*, 2018; Gadhi *et al.*, 2019). Clove extracts either inhibited the growth of the pathogen or inhibited germination of spores sometimes completely or to some extent depending on the concentration of the bioactive compounds present in the extract (Ayoola *et al.*, 2008; Sanit, 2016). The antifungal activity of clove is attributed to the presence of compounds such as eugenol whose concentration in the plant may be influenced by geography, climate, the topography of growth location as well as the variety or cultivar of the plant and susceptibility of the pathogen involved (Amelia *et al.*, 2017; Uddin *et al.*, 2017). The mode of action of compounds such as eugenol is by impairing the integrity of cell walls of a pathogen such as the chitinous cells of *Alternaria* (Fernandes *et al.*, 2014; Olea *et al.*, 2019). This activity resultantly ends the development of the pathogen, eventually killing it. Antifungal activity of clove against other types of the pathogen has also been recorded such as but not limited to *Phytophthora, Aspergillus, Glomerella, Penicillium* (Bowers and Locke, 2004; Hasheminejad *et al.* 2019; Oros and Kallai, 2019; Nadjabbasi *et al.*, 2020).

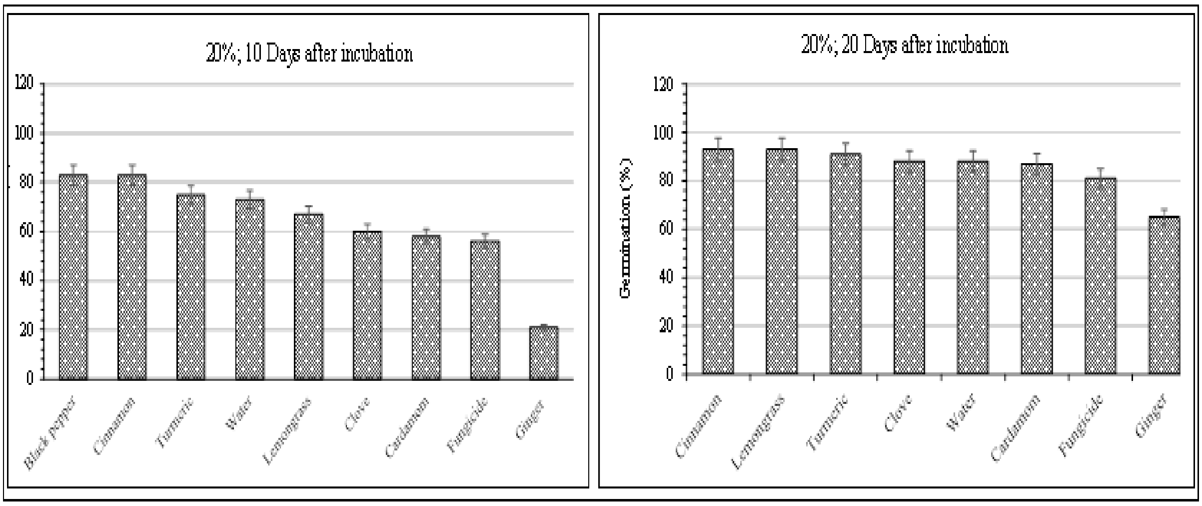

Fig. 3. Germination percentage of tomato seeds treated with 20% concentration of plant extracts at 10 and 20 days after incubation.

According to the findings in the current study, turmeric's antifungal activity against *Alternaria, Pythium* and *Fusarium* ranged between 60 – 100% and similar activity has been reported against pathogenic species related to tomato as well as other crops (Amsaraj and Prasad, 2020; Pun *et al.*, 2020; Nagaraju *et al.*, 2020). The mode of action exhibited by turmeric extracts is complete inhibition of mycelial growth and conidial germination depending on dose-dependent concentrations (Pipliwal *et al.*, 2017; Rex *et al.*, 2020). According to Wang *et al.* (2019), compounds present in turmeric oil inhibited the growth of *Phytophthora capsici* by rapturing the cell membrane of the causal agent of blight in pepper. The antifungal activity of turmeric is attributed to the compounds present in the plant such as turmerone, *ar*-turmerone, curcumol, *beta*-elemene and curlone whose evidence of antifungal activity has been reported against plant pathogenic fungi (Lee *et al.*, 2003; Sahoo *et al.*, 2019; Wang *et al.*, 2019). Antimicrobial activity of turmeric has been reported against different genera of fungi such as *Phytophthora, Puccinia, Rhizoctonia, Colletotrichum* (Radwan *et al.*, 2014; Wongkaew and Sinsiri, 2014; Han *et al.*, 2018) all of which cause different diseases in tomato and other crops.

Ginger extracts inhibited the growth of *Alternaria, Pythium* and *Fusarium* by between 54 – 100%. Similar levels of antifungal activity have been reported by studies involving the present and other related pathogens (Zagade *et al.*, 2012; Prasad *et al.*, 2018; Naik *et al.*, 2020). The activity of ginger extracts against different pathogens is reportedly varied due to the presence and abundance of bioactive compounds such as gingerols, geranial, alpha-zingiberene, beta-sesquiphellanderene, aromatic-curcumene, aromatic-beta-bisabolene as well as the susceptibility of the pathogens (Manasa *et al.*, 2013; Koch *et al.*, 2017; Munda *et al.*, 2018). Ginger extracts have been reported to inhibit the growth of pathogens by lysing the fungal structures (Ravi *et al.*, 2017). Ginger extracts or oils have been reported effective against species of *Penicillium*, *Corticinium, Rhizoctonia, Aspergillus,* (Okigbo *et al.*, 2018; Sinha *et al.*, 2018).

The antifungal activity of black pepper against *Alternaria, Pythium* and *Fusarium* in the current study ranged between 63-100%. Effectiveness of black pepper as an antifungal has been reported against either of the pathogens studied herein affecting tomato or other crops (Pattnaik *et al.*, 2012; Yadav *et al.*, 2018). While this and other studies exhibit the growth inhibitory potential of black pepper against fungal pathogens, Yadav *et al.* (2018) reported a growth promotion in *Alternaria ochroleuca* an activity associated with the ability of the pathogen to detoxify allelochemicals present in *Piper nigrum*. The antifungal potential of black pepper is attributed to the presence of bioactive compounds such as piperine, carene, D- limonene, *beta*- pinene and caryophyllene among others (Tran *et al.*, 2019; Yohannes *et al.*, 2019). Black pepper extracts or oils have been reported effective against other genera of fungi such as *Aspergillus, Ascochyta, Verticillium, Botrytis, Penicillium* among others (Nikolic *et al.*, 2015; Oros and Kallai, 2019).

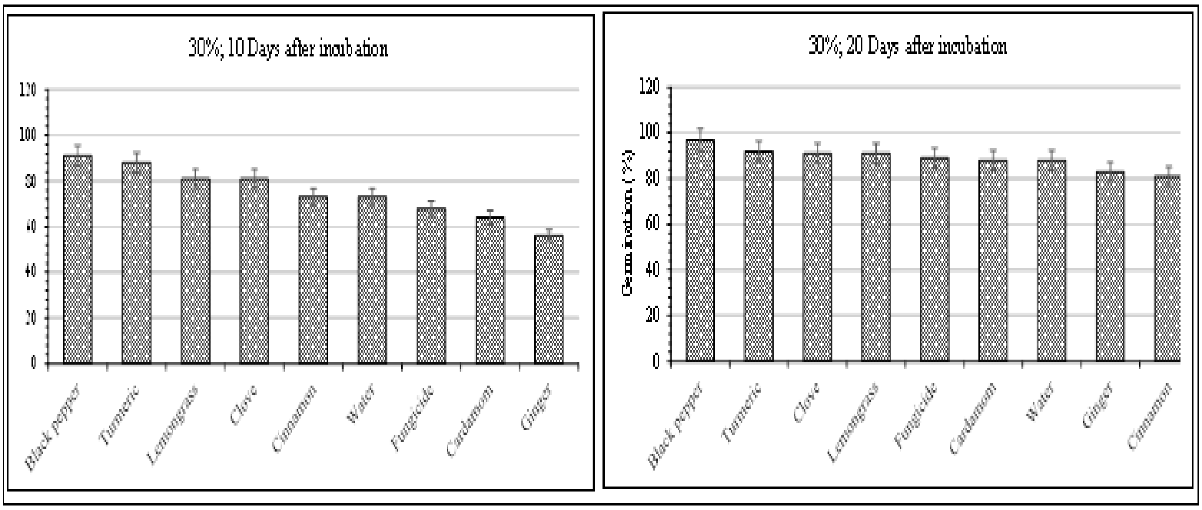

Fig. 4. Germination percentage of tomato seeds treated with 30% concentration of plant extracts at 10 and 20 days after incubation.

The comparatively lower activity of cardamon, cinnamon and lemongrass varied across the pathogens. Higher antifungal activity of these plant extracts has however been reported by different studies and against different pathogens (Al-Shemmary *et al.*, 2018; Clerck *et al.*, 2020). Nevertheless, findings in other studies agree with the observations in the current study reporting average to the low antifungal activity of extracts belonging to cardamom, cinnamon and lemongrass. The antifungal activity is subject to the presence and concentration of bioactive compounds as well as the composition of fungal cells of the pathogens (Kapoor *et al.* 2008; Hameed *et al.*, 2016; Sattary *et al.*, 2020).

The comparatively low activity of the fungicide against *Alternaria* and *Fusarium* is explained by the fact that the chemical is designed for the management of late blight disease of tomato and potato. Late blight is caused by *Phytophthora infestans*, an oomycete belonging to the same family as *Pythium* whose growth was completely inhibited by the fungicide.

The differences observed in the sensitivity of the pathogens towards the extracts are subject to the composition of their cell walls. *Alternaria* and *Fusarium* were less sensitive to the extracts compared to *Pythium*. The cell walls of *Fusarium* and *Alternaria* are made up of chitin and glucan while *Pythium* is made up of glucan and cellulose (Cooper and Aranson, 1967; Schoffelmeer *et al.*, 1999; Fernandes *et al.*, 2014). While both chitin and cellulose are polysaccharides, the former has a semi-crystalline structure which makes its solubility challenging unless under strong polar solvents (Pillai *et al.*, 2009). The presence of chitin in the fungal cell walls, therefore, protects them from harmful environments and guarantees their development and survival. Consequently, the plant extracts in the current study that showed high growth inhibition activity against *Fusarium* and *Alternaria* viz clove, turmeric and black pepper have great potential to manage diseases caused by the pathogens. The high activity of clove, black pepper and ginger against *Pythium* indicates the ability of the spices to effectively manage the pathogen. The lipophilic nature of major bioactive compounds in clove, ginger and black pepper gives them the potential to dissolve and digest the cellulosic cell wall of *Pythium* thereby effectively managing damping-off disease caused by the pathogen (Yohannes *et al.*, 2018; Olea *et al.*, 2019).

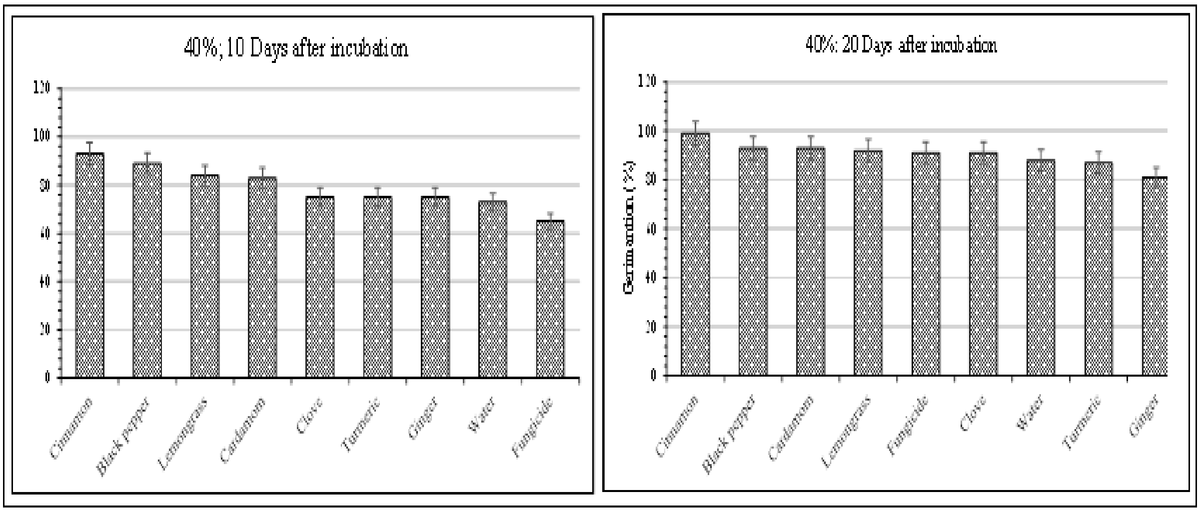

Fig. 5. Germination percentage of tomato seeds treated with 40% concentration of plant extracts at 10 and 20 days after incubation.

All the treatments investigated in this study influenced the germination rate of Money Maker® tomato seeds. Among the plant extracts, the highest germination was recorded in seeds treated with cinnamon, black pepper, cardamom, lemongrass, turmeric, clove and ginger in that order with comparisons drawn from the negative and positive control. Different concentrations of plant extracts influenced the germination of the seeds. The more dilute treatments allowed a higher germination percentage within the first ten days of incubation. The germination rates reported in this study have been reported elsewhere, either involving tomato or other plant seeds. Nwachukwu and Umechuruba (2001) reported a germination rate of 50 – 53% in the seeds of African yam bean (*Sphenostylis stenocarpa*) treated with lemongrass extracts. This was however a lower germination rate compared to 92% of tomato seeds treated with lemongrass as reported in the current study. Sorghum (*Sorghum bicolor*) seeds treated with lemongrass harmlessly transitioned into seedlings and the extract was recommended as a seed dresser by Somda *et al.* (2007).

The effect of turmeric and clove reported in the current investigation mirrors that of Suwitchayanon and Kunasakdakul (2009) who reported a germination percentage of between 82 and 92% in Chinese kale seeds treated with clove and turmeric respectively. The concentrated treatments of ginger did not allow germination of seed for up to 10 days and only supported an 11% germination rate at the end of the experiment in the current study. However, according to Karabuyuk and Aysan (2018), ginger extracts did not reduce the germination rate in tomato seeds treated against bacterial speck disease caused by *Pseudomonas syringae* pv. *tomato*. Similarly, Chandel and Kumar (2017) reported a germination rate of 84 and 88% in garden pea (*Pisum sativum*) seeds treated with ginger and turmeric respectively with increased dry weight in seeds and seedlings treated with turmeric extracts. According to Pan *et al*. (2008), seeds of the soybean (*Glycine max*) and chive (*Allium schoenoprasum*) treated with ginger extracts recorded reduced germination rates and retarded seedling development due to interference with physiological processes among others, water intake. The authors attributed this finding to the presence of water soluble allelochemicals found in the ginger plant.

The high concentrations of spice extracts deterring germination in the current study may be due to allelopathic effects associated with the presence and concentration of bioactive compounds (Siddiqui, 2007; Han *et al*., 2008; Findura *et al*., 2020). While the concept of allelopathy is important in the control of weeds, the current study showed deleterious effects on the seeds and subsequently germination.

The commercial fungicide used in this study as a positive control recorded a maximum germination rate of about 90%. Black pepper, cardamom, cinnamon and lemongrass extracts however exceeded this percentage by registering up to 98% germination. This finding is contrary to that of Alam *et al*. (2014) who reported that the highest germination of about 95% was recorded in seeds of chili (*Capsicum annum*) treated with a fungicide as compared to plant extracts of neem, garlic, ginger and allamanda leaves.

In the current study, black pepper extracts supported a germination rate of about 97%. Being that Siddiqui (2007) reported black pepper leachates inhibited germination and retarded early development of black gram (*Vigna mungo*) seeds, the high germination rate in the current study can only be supported by the concentration of the extracts used to treat the tomato seeds. The authors concluded that high concentrations of the black pepper leachates were responsible for the reduced germination as well as impaired physiological aspects such as chlorophyll synthesis (Siddqui, 2007). Agreeably, high concentrations of black pepper supported germination of about 11% within ten days of incubation but lower concentrations allowed over 90% in the current study.

The most concentrated solution of cinnamon supported a germination percentage of about 66% while the least supported about 98% germination in the current study. Contrary to this finding, Wolf *et al.* (2008) reported that concentrated cinnamon oil had negative effects on the germination of cabbage (*Brassica oleracea*) seeds.

Conclusion

Botanical preparations have already been reported to have antimicrobial activity against a wide range of seed and soil-borne pathogens. The extracts investigated in this study all inhibited the growth of the soil and seed-borne pathogens by significant extents, some even better than the chemical fungicide used as a positive check. The extracts also influenced the germination of tomato seed and the more dilute concentrations stimulated and supported higher germination percentage compared to the seeds treated with distilled water. This study recommends that upon consideration of either of the plants studied herein as a seed treatment, an appropriate dilution should be identified to eliminate seed infection and at the same time support a high germination rate. Clove, black pepper, ginger and turmeric were predominantly effective against *Pythium*, completely inhibiting its growth and therefore this study recommends their consideration as a management option for damping-off in tomato seedbeds.

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