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Research Article

Evaluation of Tomato Seed Health and Sustainable Management Practices Using Biological and Chemical Approaches

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Abstract

An experiment evaluated the seed health status of eight tomato varieties viz. Binatomato-6 (V1), Binatomato-7 (V2), Binatomato-10 (V3), Binatomato-11 (V4), Binatomato-12 (V5), Binatomato-13 (V6), Ratan (V7) and Roma VF (V8) alongside sixteen bio-agents and fungicide treatments, including controls and various concentrations of garlic, neem, Allamanda, *Trichoderma* spp., and Sinkar. The results indicated that Binatomato-13 had the highest percentage of healthy seeds (84.42%), lowest discoloration (3.32%) and highest germination rate (93.0%). Six seed-borne fungi were identified, with Ratan showing high susceptibility (20.0%) while Binatomato-12 effectively reduced fungal incidence (7.64%). Neem extract at a 1:1 concentration achieved the highest vigor index (1433.20) and significantly improved normal seedling development (79.67%). Neem also reduced the incidence of *A. flavus*, *F. oxysporum*, and other fungi. Consequently, Binatomato-13 was the best-performing variety and Neem at 1:1 was the most effective plant extract for reducing seed-borne infections.

Keywords: Health, Management, Quality, Seed, Tomato

Introduction

Bangladesh, an agro-based country, has 45% of its labor force engaged in agriculture (BBS, 2016). Among vegetables, tomato (*Solanum Lycopersicum L.*) is significant in

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consumption, production, and commercial use, especially for canning (Chowdhury, 1979). Rich in vitamins A, B, and C, along with minerals like calcium and iron, tomatoes contain lycopene, an antioxidant that may reduce prostate cancer risk (Naika *et al*., 2005). However, tomato production faces constraints such as pests, diseases, weeds, and postharvest losses. Seedborne diseases are critical, with over 200 reported globally (Jones *et al*., 1991). Pathogenic fungi impact seed quality and germination, transmitting diseases from seeds to seedlings (Islam and Borthakur, 2012). Common seedborne diseases in Bangladesh include early blight (*Alternaria solani*), germination reduction (*Aspergillus flavus*), and Fusarium wilt (*Fusarium oxysporum*), leading to yield losses of 60% to 70% (Kirankumar *et al*., 2008). Effective management of these diseases is essential for producing high-quality seeds. While chemical treatments are common (Braga *et al*., 2010), biological agents like *Trichoderma* spp. show promise in crop protection (Howell, 2003). This research aims to identify seed-borne fungi in nine tomato varieties and assess biological control agents against chemical fungicides.

Materials and Methods

The experiment was conducted at the Seed Pathology Centre (SPC) and the Department of Seed Science and Technology, Bangladesh Agricultural University (BAU), Mymensingh, from July to November 2020. Eight tomato varieties viz. Binatomato-6, Binatomato-7, Binatomato-10, Binatomato-11, Binatomato-12, Binatomato-13, Ratan, and Roma VF were evaluated against fungal pathogens and sixteen treatments viz. control (T0), Garlic (w/v) @ 1:1 (T1), 1:2 (T2), 1:3 (T3), Neem (w/v) @ 1:1 (T4), 1:2 (T5), 1:3 (T6), *Allamonda* (w/v) @ 1:1 (T7), 1:2 (T8), 1:3 (T9), *Trichoderma* sp. (w/v) @ 1:1 (T10), 1:2 (T11), 1:3 (T12), Sinkar (w/v) @ 1:1 (T13), 1:2 (T14) and 1:3 (T15) were used for the study, including bio-agents and fungicides. Seed quality assessment included purity analysis, where seeds were separated based on morphology and size, with purity percentage calculated using ISTA (2022) methods. A

representative seed sample was taken. The seeds were separated into components based on morphology, size, and other characteristics. Each component was weighed and purity Percentage were calculated by this formula [(Weight of Pure Seed/Total Sample Weight) ×100] (ISTA, 2022). Moisture test was calculated by oven-dry method. A representative seed sample of tomatoes were taken for the test. The initial mass of the tomato seeds was recorded. The sample were placed in an oven at temperature of 105°C for 24 hours, until a constant mass was achieved. After drying, the sample were allowed to cool in a desiccator and the final mass was recorded. The moisture content was calculated as a percentage [Moisture Content (%) = (wet weight - dry weight) x dry weight / 100]. Germination test and determination of vigor index were also done following plastic pot method (Warham, 1990). Vigor index was calculated by following formula [Vigor index (VI) = Germination (%) × {Root length (cm) + shoot length (cm)}]. Soil was sourced from the Plant Pathology Field

Laboratory, BAU. Seed inspection for seedborne mycoflora was conducted using naked-eye and microscopic methods, focusing on uniformity and discoloration (Peksen and Peksen, 2003).

Identification of seed-borne fungi followed the methods of Ellis (1976) and Neergaard (1979), with surface sterilization of seeds using sodium hypochlorite. Fungal growth was examined after incubation at 20-25°C. Bacterial isolation involved sterilization, maceration of seeds, and serial dilution onto nutrient agar, with biochemical tests for identification (Srinivasan, 2017) (Plate 1-4).

Morphological and biochemical characteristics were assessed, and seeds were treated with biological and chemical fungicides before germination testing The experiment employed a completely randomized design (CRD) with three replications, and data analysis was conducted using MSTAT statistical software

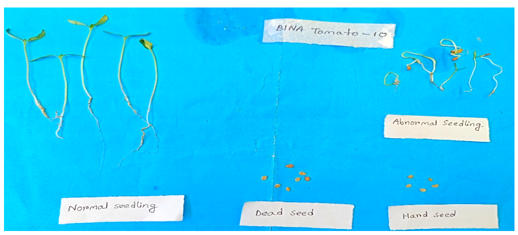

Plate 1. Categories of germinated seedlings (Binatomato-10)

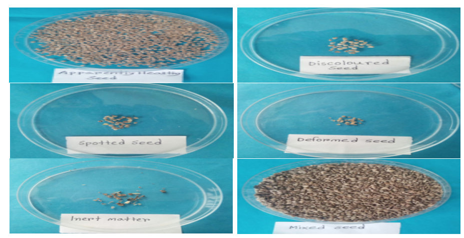

Plate 2. Different categories of inspected dry seeds

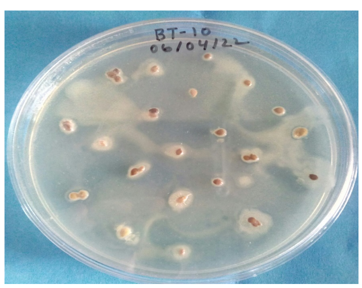

Plate 3. Isolation of bacteria from tomato seeds (incubated method)

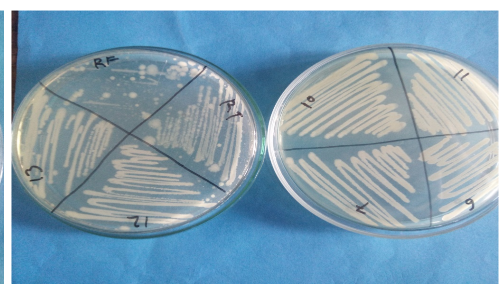

Plate 4. Pure culture of bacteria on NA medium

Results and Discussion

Purity and moisture test: The study found that Binatomato-13 had the highest seed purity (98.8%), while Ratan had the lowest (96.2%). All varieties had ideal moisture levels (7-8%), minimizing fungal and bacterial risks (Table1).

Table 1. Purity test and moisture content of different varieties of tomatoes

Variety	Pure seed (g)	Other seed (g)	Inert matter (g)	% Purity	Moisture content (%)
Binatomato-6	9.83 ab	0.11 cd	0.06 c	98.30 abc	7.80 ab
Binatomato-7	9.73 d	0.12 c	0.15 a	97.30 c	7.60 bc
Binatomato-10	9.84 ab	0.12 c	0.04 d	98.40 abc	7.30 cde
Binatomato-11	9.76 cd	0.16 a	0.08 b	97.60 bc	7.20 de
Binatomato-12	9.80 bc	0.12 c	0.08 b	98.00 abc	7.10 e
Binatomato-13	9.88 a	0.10 d	0.02 e	98.80 a	7.30 cde
Roma VF	9.85 ab	0.12 c	0.03 de	98.50 ab	8.00 a
Ratan	9.62 e	0.14 b	0.15 a	96.20 d	7.50 bcd
Level of sig.	0.01	0.01	0.01	0.01	0.01
LSD $_{(0.05)}$	0.06	0.02	0.02	1.03	0.29
CV (%)	0.3	3.2	4.32	0.6	2.19

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of significance.

Binatomato-13 showed the highest seed purity due to fewer contaminants. Efficient seed cleaning and 7-8% moisture reduce fungal and bacterial infection risks (Ellis, 1992; Jayaraman and Kalyanasundaram, 2009).

Seed dry inspection test: Binatomato-13 also had the highest proportion of apparently healthy seeds (84.42%), whereas Ratan showed the lowest (54.33%), with a notable amount of discolored and deformed seeds (Table 2). (Table 2 and Plate 2).

Table 2. Seed health evaluation by dry seed examination

Variety	Apparently healthy seed (%)	Discolored seed (%)	Spotted seed (%)	Deformed seed (%)	Inert matter (%)
Binatomato-6	82.83 ab	6.33 c	4.67 d	4.92 e	1.25 e
Binatomato-7	81.42 b	5.5 cd	7.83 c	3.5 fg	1.5 e
Binatomato-10	81.90 b	3.92 e	5.32 d	6.46 d	2.77 c
Binatomato-11	75 c	6.08 cd	7.00 c	8.75 b	2.67 c
Binatomato-12	83.5 ab	5.27 d	4.63 d	4 f	2.6 cd
Binatomato-13	84.42 a	3.32 e	7.50 c	3.02 g	2.08 d
Roma VF	54.33 e	12.25 a	13.43 a	13.27 a	6.42 a
Ratan	72 d	8.67 b	9.77 b	6.95 cd	2.47 cd
LSD $_{(0.05)}$	2.26	0.88	1.06	0.73	0.54
Level of sig.	0.05	0.05	0.05	0.05	0.05
CV (%)	1.72	8.10	8.17	6.56	11.41

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of significance.

From this study, the variety Binatomato-13 also attain maximum quality like purity and healthy seeds with highest significant reduction in inert matter included discolored, spotted and deformed seeds in the present study might be due to perfect moisture content and qualitative seeds. Similarly, (Tekrony *et al*., 1980) reported that the maximum qualitative seeds may influence the dry matter accumulation. This finding is fully agreed the present findings.

Seed health test: Fungal infection was most prevalent in Ratan (20%), with Binatomato-11 (11.4%) and the lowest in Binatomato-12 (7.64%). Six seed-borne fungi were identified, with *Aspergillus flavus* and *Rhizopus stolonifer* being the most common pathogens, corroborating previous findings on tomato seed pathogens (Nishikawa et al., 2006; Mehrotra and Agarwal, 2003). Germination rates varied significantly, with Binatomato-13 achieving 98% germination, while Ratan recorded only 76% (Fig. 2).

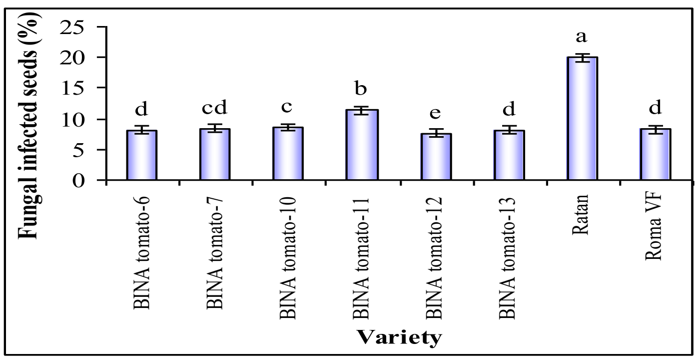

Fig. 1. Percentage of seed infection in different varieties of tomato

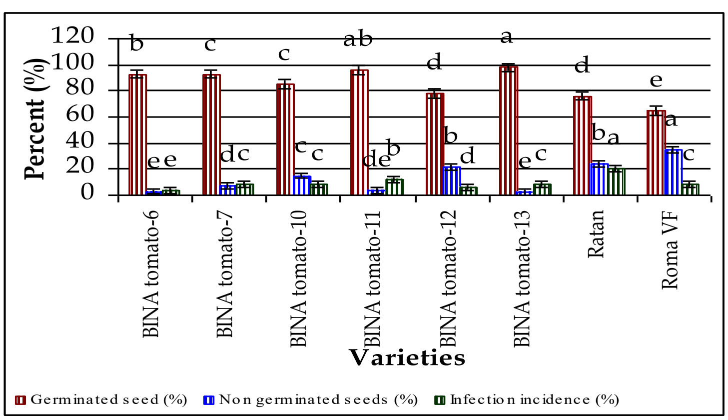

Fig. 2. Germination test of different varieties of tomato using blotter method

Table 3. Percent incidence of seed–borne fungi in eight different varieties of tomato

Seed-borne fungi	Incidence of seed –borne fungi (%)						Total
	A. flavus	*A. niger*	*F. oxysporum*	*C. lunata*	*Rhizopus spp.*	*Penicillium spp.*	
Binatomato-6	3.53 c	4.67 a	0.00 d	0.00 f	0.00 f	0.00 b	8.20 c
Binatomato-7	0.00 e	0.00 c	2.58 b	3.40 b	2.47 d	0.00 b	8.45 c
Binatomato-10	2.30 d	0.00 c	3.12 a	2.36 c	0.00 f	0.83 a	8.61 c
Binatomato-11	0.00 e	0.00 c	0.00 d	6.00 a	5.40 a	0.00 b	11.4 b
Binatomato-12	4.30 b	0.00 c	0.00 d	0.00 f	3.34 b	0.00 b	7.64 c
Binatomato-13	2.57 d	4.60 a	0.00 d	0.67 e	0.34 e	0.00 b	8.18 c
Ratan	11.0 a	3.00 b	2.33 c	1.33 d	2.34 d	0.00 b	20.0 a
Roma VF	4.00 bc	0.00 c	0.00 d	1.34 d	2.87 c	0.00 b	8.21 c
Level of sig.	0.01	0.01	0.01	0.01	0.01	0.01	0.01
$LSD_{(0.05)}$	0.65	0.36	0.21	0.25	0.32	0.01	1.03
CV (%)	10.69	13.26	11.73	7.64	8.74	3.41	5.81

column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differs significantly as per 0.05 level of significance.

In this study, seed-borne fungi such as *Fusarium oxysporum*, *Rhizopus stolonifera*, *Curvularia lunata*, *Aspergillus flavus*, *A. niger* and *Penicillium* spp. were isolated from tomato seeds. Previous studies (Nishikawa *et al*., 2006; Mehrotra and Agarwal, 2003; Telang, 2010; Hamim *et al*., 2014) similarly found these fungi in tomato seeds ().

Biochemical criteria of pathogenic bacteria on tomato seeds: In evaluating seedborne bacterial pathogens, *Erwinia carotovora s*ubsp. *carotovora* was found on the seed surface, confirming its seed-borne nature, with disease incidence at 12% (Table 4). Physical and chemical seed treatments showed efficacy in controlling *E. carotovora*, with sodium hypochlorite sterilization proving effective (Plate 6).

Table 4. Characterization of *Erwinia carotovora* subsp. *carotovora* isolates obtained from different varieties of tomato seeds

Isolated variety	Anaerobic growth	Gram staining	KOH solubility test	Yellow pigment on YDC	Pathogenecity test
Binatomato-6	+	-	+	+	+
Binatomato-7	+	-	+	+	+
Binatomato-10	+	-	++	+	++
Binatomato-11	+	-	+	+	+

Isolated variety	Anaerobic growth	Gram staining	KOH solubility test	Yellow pigment on YDC	Pathogenecity test
Binatomato-12	+	-	+	+	+
Binatomato-13	+	-	+	+	+
Ratan	+	-	++	+	+
Roma VF	+	-	+	+	+

+ = positive, - = negative, ++= strongly positive

This study found that physical chemical seed treatments were effective against *E. carotovora* subsp. *carotovora.* Sodium hypochlorite (1% for 3 minutes) effectively sterilized seeds. The bacterium's characteristics suggest seed-borne transmission, supported by studies (Mathur and Manandhar, 2003; Singh and Mathur, 2004).

Germination rate and determination of vigor index: In this study, Binatomato-13 showed the highest germination (93%) and vigor index (1239.31), while Ratan had the lowest germination (75.67%) and vigor index (573.33). Pathogenic fungi like *C. lunata*, *F. oxysporum* and *A. solani* significantly reduced germination rates in tomato seeds (Table 5).

Table 5. Percentage of seed germination, seedling vigor and percent germination category of eight varieties of tomato in sand method

Tomato varieties	Germination (%)	Required days for germination	Mean shoot length (cm)	Mean root length (cm)	Vigor index	Normal seedling	Abnormal seedling	Dead seed	Hard seed
Binatomato-6	89 c	5 f	6.87 a	4.6 c	988.83 bc	83.66 ab	6.00 ab	4.000 e	4.666 cd
Binatomato-7	91 b	7 e	6.5 a	6.13 bc	1117.33 ab	86.33 a	5.50 abc	4.333 e	3.666 d
Binatomato-10	82 e	8 d	6.76 a	5.85 c	1,002.02 bc	70.33 de	7.50 a	10.00 bcd	12.66 ab
Binatomato-11	86 d	8 d	7.13 a	7.3 a	1208.98 a	77.33 bcd	3.00 d	9.666 bcd	9.666 abc
Binatomato-12	87 c	9 c	6.5 a	7 ab	1142.5 a	64.00 e	5.00 bcd	16.66 a	14.66 a
Binatomato-13	93 a	9 c	6.3 a	7.37 ab	1239.31 a	84.00 ab	5.00 bcd	6.33 de	4.000 d
Ratan	75.67 f	10 b	5 b	3 d	573.33 d	74.33 cd	3.50 cd	11.00 bc	11.33 ab
Roma VF	85 d	12 a	7.4 a	5 cd	1022 c	72.33 d	5.50 abc	13.33 ab	8.000 bcd
$LSD_{(0.05)}$	1.37	0.81	0.99	1.12	107.10	7.72	2.49	4.24	5.61
Level of sig.	0.05	0.01	0.05	0.05	0.05	0.05	0.01	0.05	0.05
CV	0.92	3.15	9.06	10.35	6.08	5.85	29.72	26.81	38.74

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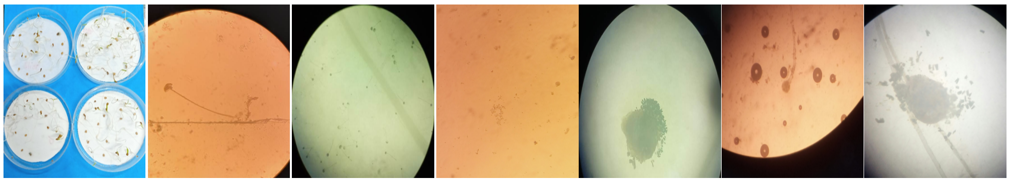
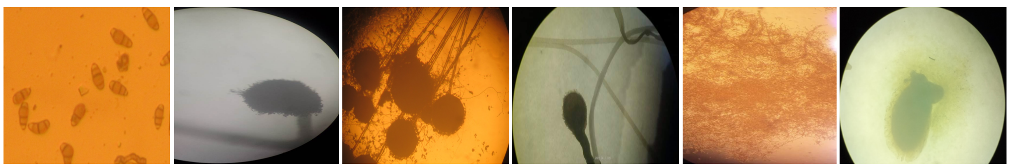


Seed health test by blotter method | *R. stolonifera* under microscope | *R. stolonifera* on infected seed | *Penicillium spp*. under microscope | *Penicillium sp*. on infected seed | *Aspergillus flavus* under microscope | *A. flavus* on infected seed



Curvularia lunata under microscope | *C. lunata* on infected seed | *Aspergillus niger* under microscope | *A. niger* on infected seed | *Fusarium oxysporum* under microscope | *Fusarium oxysporum* on infected seed

Plate 5. Six seed–borne pathogen detected on tomato seeds

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Gram staining of *Erwinia carotovora* subsp. *carotovora* | KOH solubility test | Pathogenesity test | *Erwinia carotovora* subsp. *carotovora*

Plate 6. Biochemical test results of different bacterial isolates

Impact of seed treatments on germination, vigor index and seedlings: In this study, seed treatments with plant extracts, bio-agents, and fungicides significantly improved Ratan tomato seed quality. Garlic (1:1 w/v) resulted in the highest germination (93.33%) and Neem (1:1 w/v) had the highest vigor index (1433.2). Untreated seeds showed the lowest germination (75.67%) and vigor index (573.33). The longest shoot (8.20 cm) was from *Allamonda* (1:3 w/v), and the longest root (7.97 cm) from *Trichoderma* (1:2 w/v) treatments. Neem-treated seeds had the lowest abnormal seedlings (9.67%) and lowest percentages of dead (4.33%) and hard seeds (2.33%), while untreated seeds had the highest abnormal seedlings (21.33%) (Table 6).

Table 6. Effect of seed treatment with plant extracts, bio–agents and fungicide on percent germination and vigor index (Variety Ratan)

Treatment	Germination (%)	Shoot length (cm)	Root length (cm)	Vigor index	Normal seedling (%)	Abnormal seedling (%)	Dead seed (%)	Hard seed (%)
Control	75.67 c	5.0 c	3.0 d	573.33 f	57.00 c	21.33 a	14.33 a	10.00 a
Garlic @ (1:1) w/v	93.33 a	6.5 b	5. 17 c	1088.8 e	79.67 a	11.00 b	5.00 cd	4.33 bcd
Garlic @ (1:2) w/v	91.33 ab	7.17 ab	8.00 a	1384.3 ab	79.33 ab	10.33 b	7.00 bcd	3.33 cd
Garlic @ (1:3) w/v	89.00 ab	7.17 ab	5.87 bc	1163.8 de	73.00 b	13. 33 b	7.33 bcd	6.00 b
Neem @ (1:1) w/v	92.oo ab	7.67 ab	7.97 a	1433.2 a	79.67 a	9.67 b	4.33 d	2.33 d
Neem @ (1:2) w/v	87.00 b	6.87 ab	7.37 ab	1241.4 abcde	75.67 ab	13.67 b	8.00 bcd	4.33 bcd
Neem @ (1:3) w/v	88.33 ab	7.77 ab	7.13 ab	1315.0 abcd	78.00 ab	12.00 b	7.67 bcd	4.67 bcd
Allamonda @ (1:1) w/v	90.00 ab	6.5 b	7.00 ab	1218.2 bcde	75.00 ab	12.67 b	7.33 bcd	5.67 bc
Allamonda @ (1:2) w/v	91.00 ab	6.93 ab	7.10 ab	1277.1 abcde	75.67 ab	10.67 b	9.33bcd	4.33 bcd
Allamonda @ (1:3) w/v	86.67 b	8.2 a	6.03 bc	1234.3 abcd	77.00 ab	12.00 b	7.33bcd	4.00 bcd
Trichoderma spp.@ (1:1) w/v	87.67 ab	6.70 b	5.83 bc	1097.1 e	76.00 ab	15.00 b	5.00 cd	4.00 bcd
Trichoderma spp.@ (1:2) w/v	88.33 ab	7.67 ab	7.97 a	1371.3 abc	75.67 ab	12.33 b	10.33 ab	4.33 bcd
Trichoderma spp.@ (1:3) w/v	86.33 b	6.76 b	6.77 abc	1186.0 cde	73.33 ab	11.67 b	10.33 ab	4.67 bcd
Sinkar @ (1:1) w/v	90.33 ab	7.10 ab	7.33 ab	1163.8 abcd	73.00 b	12.00 b	7.00 bcd	4.67 bcd
Sinkar @ (1:2) w/v	87.00 b	7.57 ab	6.23 abc	1201.0 bcde	76.00 ab	11.67 b	7.00 bcd	5.33 bc
Sinkar @ (1:3) w/v	89.00 ab	7.90 ab	7.13 ab	1337.9 abcd	74.67 ab	11.00 b	10.33 ab	4.00 bcd
$LSD_{(0.05)}$	5.95	1.4	1.8213	197.20	6.59	5. 88	4.67	2.58
Level of Significance	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
CV	4.05	11.89	16.56	9.77	5.28	28.26	35.22	32.73

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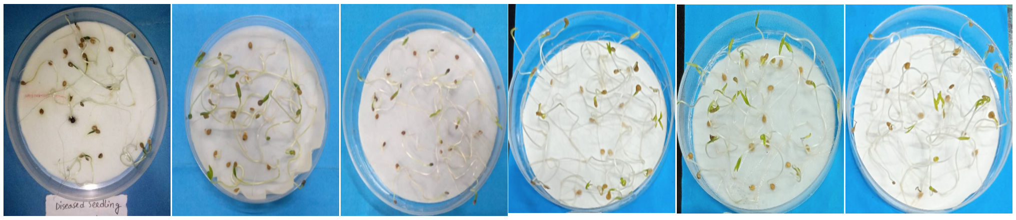

Control | Neem treated seed | Garlic treated seed | *Trichoderma spp.* | *Allamonda* | Sinkar 80WP

Plate 7. Seed treated with plant extracts, bio–agents and fungicides

Impact of seed treatments on germination and fungal infection: The study found *Allamonda* @ (1:1) w/v treated seeds had the highest standard germination (93.0%), with *Trichoderma* spp. @ (1:1) w/v also performing well (89.33%). All treatments improved germination over the control (76.33%), which had the highest fungal incidence. Garlic @ (1:3) w/v significantly reduced *A. niger* (1.06%), while Neem @ (1:1) w/v was most effective against *A. flavus*, *F.*

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oxysporum, C. lunata, *R. stolonifer*, and *Penicillium* spp. Garlic @ (1:2) and @ (1:3) w/v also effectively reduced *Penicillium* spp., with other treatments showing similar effectiveness against fungi (Table 7).

Table 7. Effect of seed treatment with plant extracts, bio–agents and fungicide on incidence of seed–borne pathogens (Variety Ratan)

Treatments	Standard germination (%)	Frequency of occurrence (%)					
		A. flavus	*A. niger*	*F. oxysporum*	*C. lunata*	*R. stolonifer*	*Penicillium spp.*
Control	76.33 c	11.33 a	10.33 a	5 a	11 a	12 a	3.27 a
Garlic @ (1:1) w/v	85.67 b	2.00 b	1.2 cde	1.13bc	1.67 b	1 f	0.76bc
Garlic @ (1:2) w/v	89 ab	2.67 b	1.78 cde	1.27 bc	2 b	2.67 bcde	0.23 c
Garlic @ (1:3) w/v	87 ab	3.67 b	1.06 e	1.13 bc	2 b	2.67 bcde	0.3 c
Neem @ (1:1) w/v	88 ab	1.67 b	2.17 cde	0.6 c	1.33 b	1 f	0.1 c
Neem @ (1:2) w/v	88.33 ab	2.00 b	2.67 bcde	0.71 c	2 b	3 bcd	0.87 bc
Neem @ (1:3) w/v	86.33 ab	2.00 b	2 cde	1.35 bc	1.67 b	1 f	1.4 b
Allamonda @ (1:1) w/v	93 a	2.00 b	2.9 bc	1.57 bc	2.67 b	2.67 bcde	1.06 bc
Allamonda @ (1:2) w/v	9 2.33 ab	2.33 b	2.43 cde	1.2 bc	2.67 b	2.33 cdef	0.7 bc
Allamonda @ (1:3) w/v	87.67 ab	2.00 b	2.83 bcd	0.75 c	3.0 b	2 cdef	0.83 bc
Trichoderma sp.@ (1:1) w/v	89.33 a	3.33 b	4.3 b	2.03 b	1.67 b	3.33 bc	0.65bc

Treatments	Standard germination (%)	Frequency of occurrence (%)					
		A. flavus	*A. niger*	*F. oxysporum*	*C. lunata*	*R. stolonifer*	*Penicillium spp.*
Trichoderma sp.@ (1:2) w/v	88 ab	3.00 b	1.5 cde	1.25 bc	1.33 b	4 bc	0.56bc
Trichoderma sp.@ (1:3) w/v	89 ab	2.33 b	1.5 cde	1.01 bc	1.67 b	1. 33 ef	0.93 bc
Sinkar @ (1:1) w/v	86.33 ab	2.00 b	2.83 bcd	1.43 bc	1.33 b	2. 33 cdef	0.6 bc
Sinkar @ (1:2) w/v	88 ab	2.67 b	2.33 cde	1.7 bc	1.67 b	3.33 bc	0.83bc
Sinkar @ (1:3) w/v	8 7.67	2.67 b	1.17 de	1.68 bc	2 b	1.67 def	0.76bc
$LSD_{(0.05)}$	7. 01	2.35	1.73	1.22	1.82	1.56	1.03
Level of sig.	0.05	0.05	0.05	0.05	0.05	0.05	0.05
CV	4.82	47.47	38.65	49.34	42.21	32.30	71.37

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly as per 0.05 level of significance.

This study assessed the impact of plant extracts, bio-agents, and fungicides on tomato seed germination, vigor index, and seedling growth. *Allamonda* and *Trichoderma* treated seeds showed the highest shoot and root length, while Neem-treated seeds exhibited the best vigor index and normal seedling percentage. Neem also recorded the lowest percentage of abnormal, dead, and hard seeds. Plant extracts were more effective than bio-agents and fungicides, aligning with findings from Ismael (2010) and Telang (2010) on seed germination and seedling vigor improvement.

Allamanda (1:1 w/v) and *Trichoderma* sp. (1:1 w/v) showed significant responses in standard germination. Garlic (1:3) effectively controlled *A. niger* and *Penicillium* spp., while Neem (1:1) was effective against *A. flavus*, *F. oxysporum*, *C. lunata*, *R. stolonifer*, and *Penicillium* sp. Plant extracts, including *Allium sativum* and *Azadirachta indica*, demonstrated greater antifungal activity than bio-agents and fungicides (Leite *et al*., 2012; Venturoso *et al*., 2011; Islam and Faruq, 2012).

Conclusion

All parameters significantly influenced seed quality and fungal incidence in tomato varieties. Binatomato-13 exhibited the best performance, while Ratan showed the poorest seed quality and was highly susceptible to fungal attack. To address Ratan's vulnerability, treatments with neem (1:1 w/v) yielded the highest vigor and disease reduction, followed closely by *Trichoderma* spp. (1:1 w/v) and garlic (1:2 w/v). This study suggests that using neem, *Trichoderma* spp. powder and garlic can effectively maintain seed quality and promote seedling growth by reducing fungal incidence, indicating that a combined treatment approach is more effective than single treatments.

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Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this manuscript.

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