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RESEARCH PAPER

Development and evaluation of different integrated disease management modules for the cost-effective control of fungal diseases of tomato

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Abstract

Tomato is one of the most popular vegetable crops nationally and internationally used by human beings either cooked and uncooked in various forms including processed products. Various types of diseases are affecting the crop ate starting from its nursery to post-harvesting. Among these, the majority of the diseases are caused by different genera of fungi. Soil-borne fungal diseases are most difficult for manage once the diseases appear in standing tomato crops. A field experiment was conducted by synthesizing different management modules to find the most economical, sustainable and eco-friendly. Based on three years of continuous experimentation on the variety Kashi Aman of tomato for the management of fungal diseases in the nursery and main field, three modules are recommended. The integrated module was the best and most economical. Alternatively, for organic and pesticide-free production of tomato variety Kashi Aman for domestic and international market biological module may be recommended in this area which will be long lasting, absolutely ecofriendly and economical. Good Agricultural Practices (G.A.P) may also be recommended in this area because the module is absolutely pesticide residue-free, sustainable, eco-friendly, long-lasting, organic-based and highly suitable for export.

Keywords: Tomato, Fungal diseases, Bioagents, Integration, Modules, Management.

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Introduction

Tomato is an important vegetable crop of our country. It is affected by many diseases among which damping-off and Alternaria blight is one of the most important and perpetual problems in this region and the losses due to early blight alone in tomatoes recorded 80 to 86% (Pandey & Pandey, 2003). Intensive cropping with continuous growing of agricultural crops is decreasing the soil health year after year. Deterioration of soil health is further aggravated due to indiscriminate and regular use of various inorganic fertilizers as well as pesticides and microbial imbalances. Soil health particularly maintenance of microbial diversity and augmentation of beneficial microorganisms are the most important concern in the present scenario of the cropping system. Vegetable-based cropping systems are more labor intensive and require more inputs, care and scientific management strategy to get good quality and quantity of vegetables. Generally, *Trichoderma* spp. has been mixed in different organic matters like FYM, vermicompost, NADEP compost and oil caked assuming it will multiply enormously on this organic substrate. Pandey (2022) has reported a higher fungi population (1.18×10^4 cfu g^{-1}) in comparison to NADEP compost (5.3×10^3 cfu g^{-1}). *Trichoderma* in combination with compost prepared from agricultural wastes was used to suppress *Rhizoctonia solani* in cucumber seedlings (Cotxarrera *et al*., 2002). *Trichoderma* species and sewage sludge compost were used to suppress *Fusarium* wilt of tomato (Borrero *et al*., 2004). However, it has never been considered that the inherent fungal, bacterial and actinomycetes of this organic matter are antagonistic or synergistic or inactive against the *Trichoderma*. Various research workers believed that a combination of antagonistic microbes with mature compost may be more efficient in inhibiting diseases than using single antagonistic microbial strains or compost alone (Sivane & Chat, 1992; Borrero *et al*., 2004; Cotxarrera *et al*., 2002).

Material and Methods

The experiment was conducted at the research farm of ICAR-Indian Institute of Vegetable Research Varanasi which has alluvial soil of sandy loam type. It was conducted for three consecutive years from 2017-18 to 2019-20 on the tomato open-pollinated variety Kashi Aman which was the most popular cultivar in this region. Six different management modules (treatments) were developed and evaluated for the management of fungal diseases starting from nursery to harvesting of tomatoes. Each treatment module comprises a set of different plant protection activities in a package to manage fungal diseases effectively from nursery damping-off to the last harvest of crop at senescence. The management package (treatments) are a Chemical module (CM), a Biological module (BM), Good Agricultural Practices (GAP) using cultural/ physical/ botanicals/ organic methods, an Integrated Disease Management module (IDM), a Research gap module (RGM) and Untreated Control. The nursery bed was solarized by white transparent polythene during hot summer from May to June. The main field was green mannured during June-July. The treated seeds were sown separately in solarized nursery beds in August. Solarization of nursery beds was an integral component of all the modules because soil solarization effectively reduced the damping-off in tomato, brinjal, chili, cabbage, and cauliflower (Pandey & Pandey, 2004). A total of 800 seeds in each treatment were sown by maintaining proper line and seed distance in one square meter area of the nursery bed and all the treatments were covered by 40 mesh insect-proof net to protect seedlings from insect vectors. The seedling stand was counted after 25 days of sowing in each treatment module of the nursery. The corresponding seedling was transplanted in first fortnight of September after its root dipping as per treatment modules. The details of the module are as follows:

Chemical module (T1)

Seed treatment by carbendazim 50% WP @0.2% and nursery drenching of pencycuron 22.9% SC @5 liter/m^2 of 0.1%, Seedling drenching by fosetyl-Al 80% WP @ 0.1% after 15 days of sowing, One spray of streptocycline 50% WP @150 ppm on seedling after 20 days of sowing, Seedling root dip in imidacloprid 17.8% SC @0.04% for 30 minutes just before transplanting, One spray of copper oxychloride @0.3% after 25-30 days of transplanting DAT. Drenching of carbendazim @0.1% once at root rot/wilt/coller rot incidence. One spray of mancozeb @0.25% and one spray of cymoxanil 8% + mancozeb 64% @0.2.5% on late blight appearance.

Biological module (T2)

Seed treatment by *Trichoderma* sp. (BATF-43-1) @1%, Nursery application of talc-based *Trichoderm*a sp. (BATF-43-1) @25 gram /m^2, Seedling root dip in slurry BATF-43-1 10 grams + 100 grams vermicompost + 250 ml water, Drenching by BATF-43-1 @1% thrice at 25 days interval started 25 DAT.

Ggood Agricultural Practices module (T3)

Soil application with neem cake @100 gram /m^2 10 days before sowing, Seed soaking in cow urine for 60 minutes, Nursery bed covering by 40 mesh nylon net, Seedling root dipping in cow dung slurry, Spot use of vermicompost @50g/plant thrice at 25 days interval, Foliar spray of micronutrient @0.2% twice at 25 days interval. Neem oil sprays @0.3% thrice at 10 days interval Azatarachtin 0.03%. Proper field sanitation for inoculum reduction particularly Sclerotinia fruit rots and wilt diseases.

Integrated Module (T4)

Seed treatment by *Trichoderma* sp. BATF-43-1, Seedling drenching of talc based BATF-43-1@1% after 15 days after sowing, Seedling root dip in imidacloprid @0.04% for 30 minutes followed by BATF-43-1 @1% for 10 minutes. Spot application of (BATF-43-1) 10 g + vermicompost 50g/plant thrice at 25 days interval started 25 DAT, One spray of copper oxychloride @0.3% after 30 days of transplanting. One spray of mancozeb @0.2.5% at flowering to fruit setting stage. One spray of cymoxanil 8% + mancozeb 64% @0.2.5% on late blight appearance.

Research gap module (T5)

Seed treatment by *T. asperllum* @0.5%+ *Bacillus subtilis* @0.5% Seedlings dip by imidacloprid @0.03% + *T. asperllum* @1%, Drenching of CRB7 (*Bacillus subtilis* as antagonistic to *Sclerotium rolfsii*, *Macrophomina phaseolina* and RKN as well as IAA producer) @1% +TRB-17 (*Stenotrophomonas*) as antagonistic to *F. oxysporum*) @1% thrice at 25-30 days interval started 25 DAT, Foliar spray of BS-2 @1% thrice at 25 days intervals after 25 DAT. Foliar spray of BS-2 @1% thrice at 25 days interval after 30 DAT. One each spray of azoxystrobin 23% SC @0.05% alternated by mancozeb @0.2% at the 8-day interval on early blight appearance.

Untreated Control (T6)

Data on marketable, unmarketable, diseases fruits, and pathogens associated were recorded in each harvest starting from the second fortnight of December and completed in the first fortnight of April comprising of about 16 harvests. Apart from the fungal diseases, observations on viral, bacterial, phytoplasmal and nematode diseases were also recorded. Foliar fungal diseases mainly early blight and late blight were commonly observed in three years and accordingly, the percent disease index was calculated 20 days after the completion of last spray schedule. Randomly ten plants were selected and scoring was carried out on 0 to 5 points disease rating scale. The root galls were recorded after uprooting five random plants from each treatment at the last harvest stage.

Results and Discussion

Effect of modules on nursery seedling stands

It was concluded based on the pooled analysis of three years data clearly indicated that T4-IDM module comprising of soil solarization of nursery beds, nursery bed covering by 40 mesh nylon net, seed treatment by carbendazim @0.2% and nursery bed drenching by pencycuron 0.1% concentration @5 liter /m^2 area followed by seedling drenching after 15 days of sowing by fosetyl-Al @0.1% in variety Kashi Aman was best with maximum seedling stand 68.81% among all the modules and in comparison, to control (57.84%). However, it was closely followed by T5-RGP where an almost similar result was observed with 66.26% seedling stand (Table 1). Earlier IDM package comprises of soil solarization of nursery beds, nursery soil application of neem cake, *Pseudomonas fluroscence, Trichoderma viride,* nylon net covering of seedlings, and one spray of streptocycline was recommended for damping-off management of tomato (Pandey *et al*., 2005).

Effect on early blight disease at foliar and fruit stage

Early blight caused by *Alternaria solani* was recorded as most destructive disease followed by late blight caused by *Phytophthora infestans*. During two years of experimentation, early blight-infected fruits were recorded maximum during 13^{th} to 16^{th} harvest in the month of March-April. Percent disease intensity as foliar stage varied from 61.71% to 86.9% in different treatment modules while 46.3% to 100% in fruit rot phase (Table 2). Pooled mean concluded that the best treatment was chemical module (T1) comprised of seed treatment by carbendazim 50% WP @0.2% and nursery drenching of pencycuron 22.9%SC @5 liter/m^2 of 0.1%, Seedling drenching by fosetyl-Al 80%WP @ 0.1% after 15 days of sowing, One spray of streptocycline 50%WP @150 ppm on seedling after 20 days of sowing, Seedling root dip in imidacloprid 17.8%SC @0.04% for 30 minutes just before transplanting, One spray of copper oxychloride @0.3% after 25-30 days of transplanting DAT. Drenching of carbendazim @0.1% once at root rot/wilt/coller rot incidence. One spray of mancozeb @0.25% and one spray of cymoxanil 8% + mancozeb 64% @0.2.5% on late blight appearance for minimum early blight incidence in comparison to control (Table 2). The early blight fruit rot severity was very high during 2017-18 while foliar blight in 2018-19. Out of total diseased fruits about 50% early blight infected fruits, 25% late blight, 20% *Rhizoctonia* infected fruits, 5% soft rots and other secondary pathogens infected fruits was observed. The fruit rot caused by *Rhizoctonia solani* was recorded from first harvest to ninth harvest as second major pathogen after *Alternaria solani*. The other diseased fruits were identified as *Rhizoctonia solani, Alternaria alternata*, *Phythium apahindermatum*, *Myrothecium rorridum*, *Sclerotium rolfsii Geotrichum candidum*, *Phytophthora nicotianeae*, *Colletotrichum capsici*, *Xanthomonoas campestris* pv. *vesicatoria* and *Erwinia carotovora* pv. *carotovora*. Surprising foliar diseases like grey leaf spot, Septoria blight, late blight, Sclerotinia rot, bacterial spot and bacterial speck were not recorded.

Table 1: Effect on nursery disease management of tomato

Treatments	*Seedling stand (%) at 25 DAS*			
	2017-18	*2018-19*	*2019-20*	*Mean*
T1-CM	73.83	56.8	58.25	62.96
T2-BM	57.83	44.4	63.75	55.32
T3- GAP	58.0	60.1	69.12	62.37
T4- IDM	80.0	56.7	69.75	68.81
T5- RGP	79.0	46.3	73.50	66.26
T6- Control	65.2	38.7	69.62	57.84
LSD (5%)	4.69	3.91	3.12	-
CV (%)	18.7	16.56	11.4	-

Table 2: Effect of modules on early blight diseases of tomato

Treatments	*Early blight (PDI)*			*Early blighted fruits (%)*		
	2017-18	*2018-19*	*Mean*	*2017-18*	*2018-19*	*Mean*
T1-CM	61.71	79.0	70.35	85.9	78.6	62.6
T2-BM	64.62	66.2	65.41	96.4	78.3	87.35
T3-GAP	68.52	78.1	73.31	95.7	62.3	79.0
T4-IDM	72.72	83.6	78.16	91.3	70.0	80.65
T5-RGP	64.63	77.2	70.91	100.0	46.3	73.15
T6-UC	70.55	86.9	78.72	94.0	63.3	78.8
LSD (5%)	1.62	7.90	-	3.33	3.50	-
CV (%)	3.05	6.52	-	4.39	6.52	-

Effect on late blight disease at foliar and fruit stage

The late blight was significantly very high (93.2%) in control in variety Kashi Aman indicating susceptibility to late blight. During cropping season 2019-20 late blight incidence in this area was very high and could not managed effectively by any of the modules due to congenial weather for the aggressive disease development. Pooled data of two years clearly revealed that late blight at foliar stage was a minimum 40.68% in T4 integrated disease management comparison to control 59.9% (Table 3). Similarly, the Phytophthora rotted

Table 3: Effect of modules on diseased tomato fruits

Treatments	*Late blight (PDI)*			*Phytophthora rotted frits (%) out of diseased fruits*			*RKN galls/plant*		
	2018-19	*2019-20*	*Mean*	*2018-19*	*2019-20*	*Mean*	*2017-18*	*2018-19*	*Mean*
T1-CM	17.6	77.99	47.75	42.0	90.0	87.0	21.43	88.9	55.16
T2-BM	20.9	77.9	49.4	38.3	90.5	64.4	17.23	114.1	65.66
T3-GAP	16.5	79.12	47.81	46.6	83.3	88.25	32.43	123.3	77.86
T4-IDM	15.4	65.97	40.68	40.0	78.7	59.35	21.97	62.7	42.33
T5-RGP	13.2	83.05	48.12	46.3	88.3	67.3	23.57	68.5	46.03
T6-UC	28.8	90.0	59.9	63.3	93.2	78.25	18.6	140.0	79.3
LSD (5%)	1.90	9.43	-	1.88	1.49	-	N/A	4.31	-
CV (%)	5.684	16.89	-	2.229	2.12	-	80.9	5.37	-

Table 4: Effect of modules on yield component of tomato

Treatments	*Marketable yield (q/ha)*				*Un-marketable yield (q/ha)*			
	2017-18	*2018-19*	*2019-20*	*Mean*	*2017-18*	*2018-19*	*2019-20*	*Mean*
T1-CM	786.3	426.0	164.2	458.83	205.2	109.33	72.06	128.86
T2-BM	685.8	459.67	233.47	459.64	229.6	113.67	113.76	152.34
T3-GAP	756.7	414.0	150.13	440.27	245.7	126.33	72.67	148.23
T4-IDM	807.4	436.67	176.40	473.49	275.8	103.33	79.57	152.9
T5-RGP	677.3	359.33	175.57	404.06	213.6	100.0	86.20	133.26
T6-UC	653.3	350.67	156.53	387.5	195.2	93.67	88.26	125.71
LSD (5%)	37.87	8.477	3.26	-	32.63	19.13	4.613	-
CV (%)	12.58	16.59	17.74	-	15.2	9.64	6.59	-

fruits were minimum 59.35% in the same module i.e. in the integrated module (T4) in comparison to control 93.2% (Table-3). The Integrated disease management module comprised of seed treatment by *Trichoderma* sp. (BATF-43-1)**,** Seedling drenching of talc-based BATF-43-1@1% after 15 days after sowing, Seedling root dip in imidacloprid @0.04% for 30 minutes followed by BATF-43-1 @1% for 10 minutes. Spot application of (BATF-43-1) 10 g + vermicompost 50g/plant thrice at 25 days intervals started 25 DAT, One spray of copper oxychloride @0.3% after 30 days of transplanting. One spray of mancozeb @0.2.5% at flowering to fruit setting stage. One spray of cymoxanil 8% + mancozeb 64% @0.2.5% on late blight appearance. Late blight incidence was almost the same in the chemical, biological and Good Agricultural Practices (GAP) modules where PDI was significantly at par to each other 78.0-79.1% (Table 3). Previously, an IPM package comprised of a seedling dip in imidacloprid, marigold planting as a trap crop, soil application of *T. viride* @2.5 kg/ha, rouging twice of virus-infected plants and removal of Alternaria infected leaves, spray of mancozeb and thiomethoxame was economical than control as well as farmers' practice (Pandey *et al*., 2005).

Additional information on root-knot nematode was also generated because *Trichoderma* and *Bacillus* were reported effective against the management of *Meloidogyne* populations in soil. Observations on root-knot nematode incidence varied from 17.2-140 galls/plant. Based on two years of pooled data revealed the integrated module (T4) was best for a minimum 42.33 galls/plant root-knot nematode (RKN) incidence as a comparison to control 79.3 galls/plant (Table 3). It is also clear from two years of data mentioned in Table 3 that the nematode infestation increased at a faster rate from first year to the second year in all the treatments.

During first year, the maximum marketable yield was 807.4 q/ha in T4-IDM followed by 760.7/ha and 756.7q/ha in T1-chemical and T3-gap respectively in comparison to control (655.3q/ha). The unmarketable yield varied from 195.2q/ha to 275.8 in different treatment modules which was about 24% of total yield (table-4). The unmarketable yield comprises of about 60% bird damage, 30% insect damage and 10% diseased. Minimum diseased fruits 3.7% were recorded in T3-GAP while a maximum 9.9% in control. Subsequently next year, a maximum marketable yield of

Table 5: Cost benefit ratio of different IDM modules for management of fungal diseases of tomato

Treatment	*Production cost (Rs.)*	*Marketable Yield (q/ha)*	*Gross income @ Rs. 600/q*	*Net Income (Rs.)*	*C: B ratio*
T1- CM	162870	458.83	275298	112428	1:1.69
T2- BM	156870	459.64	275784	118914	1:1.76
T3- GAP	157770	440.27	264162	106392	1:1.67
T4- IDM	158670	473.49	284094	125424	1:1.79
T5- RGP	158870	404.06	242436	83566	1:1.53
T6- Control	155870	387.50	232500	76630	1:1.39

459.67 q/ha was obtained in the biological module (T2). Unmarketable yield comprising a maximum 60% diseased fruits, 20% bird damage, 10% borer & *Tuta absoluta,* rest 10% abiotic stress. Third year the highest marketable yield 233.47q/ha was recorded in the biological module (T2) in comparison to control 156.53 (Table 4). Based on pooled data of three years it was concluded that T4-IDM module was best giving a maximum marketable yield 473.49 q/ha as compared to only 387.5 q/ha in control. Hewson *et al.* (1998) stated that level of control and crop yield from the IDM program are often better than the conventional method. The unmarketable yield was in propionate to the marketable yield.

Based on three years of continuous experimentation on the variety Kashi Aman of tomato for the management of fungal diseases in the nursery and main field, two modules are recommended (Table 5). The integrated module was best and most economical. Integrated module comprising of seed treatment by *Trichoderma* sp. (BATF-43-1), Seedling drenching of BATF-43-1 @1% after 15 days of sowing. Seedling root dip in imidacloprid @0.04% for 30 minutes followed by BATF-43-1@1% for 10 minutes. Spot application of BATF-43-1 @10g + vermicompost 50g/plant thrice at 25 days intervals started 25 days after transplanting, One spray of copper oxychloride @0.3% after 30 days of transplanting. One spray of mancozeb @0.2.5% at flowering to fruit setting stage. One spray of cymoxanil 8% + mancozeb 64% @0.2.5% on late blight appearance resulted maximum seedling stand 68.81%, minimum late blight severity, Phytophthora rotted fruits & root galls per plant with maximum marketable yield of 473.49q/ha and highest C:B ratio 1:1.79 which can be recommended for this area. Alternatively, for organic and pesticide-free production of tomato variety Kashi Aman for domestic and international market biological module may be recommended in this area which will be long lasting, absolutely ecofriendly and economical. Biological module comprising of seed treatment by *Trichoderma* sp. (BATF-43-1) @1%, Nursery application of talc-based *Trichoderm*a sp. (BATF-43-1) @25 gram /m^2, Seedling root dip in slurry BATF-43-1 @10 grams + 100 grams vermicompost + 250ml water, Drenching by BATF-43-1 @1% thrice at 25 days interval started 25 DAT. It resulted in no root rot and wilt diseases in the field while minimum early blight severity on foliage (65.41%), Phytophthora rotted fruits percentage was 66.4% out of total diseased fruits, maximum marketable yield (459.64 q/ha) with CB ration of 1: 1.76.

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सारांश

टमाटर राष्ट्रीय एवं अन्तर्राष्ट्रीय स्तर पर एक महत्वपूर्ण सब्जी फसल है जो मनुष्य द्वारा सब्जी के रूप में पकाकर तथा सलाद के रूप में कच्चा ही खाया जाता है। इस सब्जी फसल में पौधशाला से लेकर मुख्य फसल की तुड़ाई तक बहुत तरह की बीमारियाँ लगती हैं। इन बीमारियों में आकिाशतः फफूँद द्वारा होता है। मुख्य रूप से बीमारियों के रोगकारक मिट्टी में जीवित रहते हैं और पौधे की जड़ों को सड़ाते, गलाते रहते हैं। मिट्टी जनित रोगों की रोकथाम बहुत कठिन होता है और रासायनिक विधि से उपचार बिल्कुल ही सही नहीं है। उपरोक्त को ध्यान में रखकर फफूँद जनित बीमारियों को रोकने के लिए कई प्रकार के एकीकृत रोग प्रबंधन के अवययों को समाहित करके सात प्रकार के मोड्यूलस का परीक्षण तीन साल तक टमाटर की प्रचलित किस्म 'काशी अमन' पर किया गया। इन सभी मोड्यूल में एकीकृत रोग प्रबंधन मोड्यूल एवं जैविक मोड्यूल सबसे अधिक प्रभावशाली, सुरक्षित एवं अधिकतम लाभ देने वाला पाया गया और इसकी संस्तुति की जाती है। टमाटर के कीटनाशी रसायन मुक्त निर्यात हेतु उत्पादन, सुरक्षित, स्वस्थ एवं सफल खेती करने के लिये जैविक मोड्यूल निःसन्देह अच्छा है और निर्यातक इस विधि को अपनाकर टमाटर पैदा कर सकते हैं।