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Full Length Article

Tomato Cultivation in Bangladesh: Insights into Pest Awareness and Disease Management

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Abstract

Tomato (*Solanum lycopersicum* L.), an extensively cultivated vegetable in Bangladesh, is profoundly influenced by insect pests and diseases, adversely affecting crop yield and quality. Farmers' knowledge and perceptions about these difficulties are essential for the successful and sustainable implementation of pest control measures in tomato cultivation. This research included a comprehensive survey of 400 tomato-growing farmers across 10 districts in Bangladesh to assess their knowledge of prevalent tomato pests, diseases and existing management strategies. The results indicated that farmers have been facing pest and disease challenges for several years, listing significant pests such as fruit borers, whiteflies and aphids, as well as diseases like Tomato Yellow Leaf Curl Virus (TYLCV) and late blight as common. More than 90% of farmers indicated significant crop loss, between 30% and 49%, primarily due to various pests and diseases. A majority of farmers (78.5%) mostly used chemical pesticides, spraying them at intervals of 3-7 days while exhibiting little implementation of Integrated Pest Management (IPM). The survey showed that 71% of farmers did not have formal training in pest management, leading them to often use insecticides (mainly neonicotinoids) and fungicides (especially triazoles) every 3-7 days, with short waiting times before just of 2-3 days, which could be more harmful to food safety. The results highlight the critical need for training initiatives and the implementation of more sustainable pest control strategies to enhance tomato cultivation in Bangladesh.

Keywords: Tomato pests; Survey; Farmer perceptions; Pest management; Chemical pesticides; IPM

Introduction

Tomato (*Solanum lycopersicum* L.) is recognized as the fourth most economically significant food crop worldwide and is grown in nearly every country (Schreinemachers *et al.* 2018). This vegetable crop holds significant importance in Bangladesh, contributing to food security and providing income for smallholder farmers. This crop is grown in multiple regions, such as Rajshahi, Rangpur, Bogura and Jashore, due to the advantageous agro-climatic conditions present in the country. Data from the Bangladesh Bureau of Statistics (BBS) indicates that tomato production during the 2022-2023 agricultural year amounted to 4.1 million metric tons, with cultivation occurring over an area of approximately 80,000 ha (BBS 2023). Despite this achievement, the cultivation of tomatoes in Bangladesh encounters significant challenges posed by insect pests and diseases, which can result in considerable reductions in yield. Tomato plants experience infestations from various insect pests; however, the fruit borer (*Helicoverpa armigera* Hub.) is recognized as the most detrimental. The larvae penetrate the fruit, feeding on the internal tissue (Nasrin *et al.* 2021). The tomato leaf miner, *Tuta absoluta* (Meyrick), is one of the most destructive invasive pests of tomato crops in the world. It is one of the most significant biotic limitations on tomato production and if left unchecked, it could result in a 100% reduction in yield (Huda *et al.* 2020). Other insects, including whiteflies (*Bemisia tabaci* Gennadius), aphids (*Aphis gossypii* Glover) and thrips (*Thrips tabaci* Lindeman), cause significant harm by feeding on plants and help spread viruses such as Tomato Yellow Leaf Curl Virus (TYLCV) (Moriones and Navas-Castillo 2000; Hanssen *et al.* 2010; Kenyon *et al.* 2014; Schreinemachers *et al.* 2017a). Early Blight was observed in 85% of the fields and 90% of the

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farmers noted it as a major cause of yield loss (Nuwamanya *et al.* 2023). Additionally, bacterial wilt from *Ralstonia solanacearum* (Smith) (Mansfield *et al.* 2012) and late blight from *Phytophthora infestans* (Bary) greatly reduce tomato harvests and the quality of the tomatoes (Fry 2008; Nowicki *et al.* 2011). Weeds are one of the key problems in tomato production, as they compete for light, nutrients, water and space, resulting in reduced yields. Some usual broadleaf weeds like nightshade, cocklebur and pigweed host bugs, diseases and viruses (Pala and Karipsin 2021). Research indicates that agricultural producers in Bangladesh experience average yield reductions of 11 tons per ha as a result of these challenges (Depenbusch *et al.* 2023). To address these challenges, a significant proportion of farmers in Bangladesh rely extensively on chemical pesticides, which constitute approximately 17% of overall production expenses (Depenbusch *et al.* 2023). Relying too much on chemical methods has caused many problems, including the development of pesticide resistance in pest populations, environmental contamination and significant health hazards for farmers, such as pesticide poisoning (Schreinemachers *et al.* 2017b). Even with an understanding of these risks, numerous farmers persist in utilizing pesticides as their main method of pest management, primarily due to insufficient knowledge and limited access to alternative approaches (Schreinemachers *et al.* 2017a; Akter *et al.* 2018).

Integrated Pest Management (IPM) provides a more sustainable approach to these challenges through the promotion of a combination of biological, cultural and chemical control methods. The implementation of integrated pest management involves utilizing insect-resistant tomato varieties, engaging in crop rotation and applying biopesticides, which collectively contribute to minimizing dependence on chemical pesticides while ensuring sustained crop productivity (FAO 2021). Nonetheless, despite its advantages, the implementation of integrated pest management in Bangladesh is still minimal, attributed to insufficient training, a lack of awareness and limitations in resources (Schreinemachers *et al.* 2017b; Depenbusch *et al.* 2023). To tackle these challenges, it is crucial to comprehend farmers' knowledge, perceptions and existing pest management practices to develop effective extension programs. In Bangladesh, precise baseline data are essential for the effective management of insect pests and diseases affecting tomato cultivation. In light of this necessity, there remains a paucity of comprehensive studies examining the perceptions and management strategies of farmers regarding these challenges. It is suggested that tomato farmers may lack the comprehensive knowledge required for the precise identification of pests and beneficial insects, as well as the implementation of effective Integrated Pest Management (IPM) strategies in tomato cultivation. This study aimed to investigate the level of awareness and understanding among farmers regarding pest and disease challenges, as well as the management strategies currently utilized in prominent tomato cultivation areas of Bangladesh.

Materials and Methods

Site selection

This research was carried out during the winter of 2021 and 2022 to assess farmers' attitudes and knowledge about insect pests, diseases and weeds impacting tomato crops, as well as their management strategies throughout ten districts in Bangladesh. The chosen districts included Dinajpur (25°37'07.0"N 88°38'06.2" E), Rangpur (25°26'09.5"N 89°18'41.6" E), Rajshahi (24°27'22.2"N 88°20'24.7" E), Bogura (24°41'00.9"N 89°32'26.8" E), Dhaka (23°45'54.6"N 89°58'18.3" E), Jashore (23°15'16.4"N 89°17'46.8" E), Barishal (22°49'01.7"N 90°19'32.4" E), Cumilla (23°29'19.6"N 91°00'19.1" E), Chittagong (22°01'32.5"N 91°56'58.0" E) and Sylhet (24°48'58.6"N 91°45'22.7" E) (Fig. 1).

A multi-stage sampling method was used to guarantee a representative sample of tomato cultivators. Initially, two upazilas were randomly chosen from each district, culminating in a total of 20 upazilas for the research. A systematic random selection approach was used inside each upazila to choose farmers according to the number of tomato producers recorded in local agricultural databases.

Data collection

Data were gathered *via* in-person interviews using a prepared questionnaire including both open-ended and closed-ended inquiries. The questionnaire sought to evaluate farmers' knowledge of tomato insect pests, diseases and weeds; their perceived severity and the management strategies they used. Socio-demographic data, including age, gender, educational attainment, agricultural experience and land area, were collected to assess their impact on pest control techniques.

The questionnaire used visual aids consisting of printed photos depicting prevalent tomato pests and diseases to improve comprehension. The method enabled farmers to precisely identify and prioritize pests and diseases according to the damage witnessed in their tomato crops. We questioned 400 farmers in total, with an average of 20 responses from each selected upazila. Trained enumerators assisted data collection, ensuring consistency and accuracy throughout the interviews.

To select farmers from the twenty upazilas, we applied the following formula to calculate the total number of respondents:

$$\mathrm{n} = \frac{N}{1+N\varepsilon^2}$$

Where:
- n is the sample size,
- N represents the total number of farmers in each area and
- ε denotes the margin of error (Tuan *et al.* 2014).

Table 1: Socio-demographic status of the tomato growing farmers from 20 surveyed upazilas of Bangladesh

Factor	Category	Frequency	% Total Farmers	Mean	SD
Age (years)	15-30	53	13.2	27.51	2.21
	31-45	181	45.2	38.31	4.25
	46-60	137	34.3	52.51	4.07
	> 60	29	7.3	64.41	2.76
Gender	Male	377	94.3	-	-
	Female	23	5.7	-	-
Education level	Illiterate	89	22.3	-	-
	Only Signature	104	26.0	-	-
	Class 1-5	66	16.5	-	-
	Class 6-9	63	15.7	-	-
	SSC	52	13.0	-	-
	HSC	19	4.7	-	-
	Graduate	7	1.8	-	-
Land Type	Own	269	67.3	-	-
	Lease	59	14.7	-	-
	Borga	72	18.0	-	-
Experience in agriculture including tomato farming (years)	1-5	127	31.7	4.34	0.66
	6-10	141	35.3	7.95	1.19
	11-15	63	15.7	13.52	1.29
	> 15	69	17.3	20.99	3.84

SSC = Secondary School Certificate, HSSC = Higher Secondary School Certificate

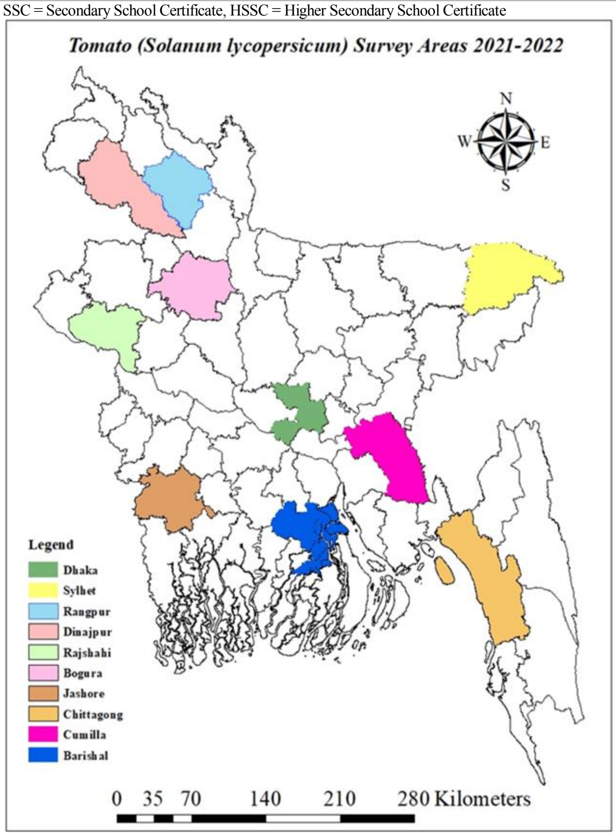

Fig. 1: Surveyed districts of Bangladesh for data collection during 2021–2022

We interviewed 400 farmers, selecting 20 from each upazila to maintain a defined margin of error of 6%. The interviews were facilitated by the Sub Assistant Agriculture Officers (SAAOs) from the corresponding upazilas.

Data analysis

We aggregated and input the collected data into SPSS (Version 26, IBM Corporation, Armonk, NY, USA) for statistical evaluation. Descriptive statistics, such as frequencies, means and standard deviations, were calculated to encapsulate the data. Moreover, MS Excel and PowerPoint were used to generate graphical representations, offering clear visual summaries of the results.

Results

Socio-demographic status of tomato farmers

Table 1 delineates the socio-demographic characteristics of the 400 tomato producers surveyed across 20 upazilas in 10 districts of Bangladesh. The predominant age group among farmers was 31-45 years, comprising 45.2%, with a mean age of 38.31 years (SD = 4.25) (Table 1). A considerable percentage (34.3%) were aged 46-60, while just 13.2% were under 30 years of age. The predominant demographic of respondents was male, with 94.3%, while females constituted just 5.7% (Table 1). Regarding education, 26% of the farmers were only able to sign their names and 22.3% were illiterate. Advanced educational degrees were uncommon, with about 1.8% of the farmers possessing a graduate degree. A majority of farmers (67.3%) owned their property, but 18% engaged in a "Borga" system (sharecropping) and 14.7% leased their land (Table 1). The farming experience in tomato production was diverse, with the majority (35.3%) possessing 6-10 years of expertise, followed by 31.7% with 1-5 years of experience.

Farm size and tomato cultivation area

Table 2 illustrates the variability in farm sizes among the surveyed farmers. Approximately 48.5% of farmers had marginal farms, including less than 0.5 ha of land, with an average of 0.22 ha allocated to tomato growing (Table 2). A considerable proportion (31.3%) managed small farms (0.51 - 1.00 ha), dedicating an average of 0.36 ha to tomato cultivation. Medium and large farms were few, with about 17% and 3.3% of farmers, respectively, possessing over 1 ha of land. The large farmers allocated a greater area (mean 0.67 ha) to tomato growing than other groups (Table 2).

Tomato varieties grown in different upazilas

As shown in Table 3, farmers in the 20 examined upazilas grew a range of tomato varieties. Several upazilas grew the most popular cultivars, including BARI Tomato-2 (Ratan), BARI Hybrid Tomato-5 and BARI Tomato-16. Furthermore, regional adaptability and preferences were reflected in the widespread cultivation of indigenous cultivars such as Bahubali, Raja and Bipul Plus (Table 3).

Table 2: Farm size and proportion of land used for cultivating tomato by the farmers from 20 surveyed upazilas of Bangladesh

Farm category	Frequency	Percentage (%)	Mean Total Land (ha.)	SD	Mean Land under Tomato Cultivation (ha.)	SD
Large (> 2)	13	3.3	3.07	0.57	0.67	0.29
Medium (1.01-2.0)	68	17.0	1.59	0.27	0.61	0.17
Small (0.51-1.00)	125	31.3	0.78	0.11	0.36	0.09
Marginal (0.01-0.50)	194	48.5	0.40	0.08	0.22	0.08

SSC = Secondary School Certificate; HSC = Higher Secondary Certificate; SD = Standard Deviation

Table 3: Tomato varieties cultivated in 20 surveyed upazilas (sub-districts) of Bangladesh

Dinajpur	Rangpur	Rajshahi	Bogura	Dhaka	Jashore	Barishal	Cumilla	Chittagong	Sylhet
BARI Tomato-2 (Ratan), BARI Tomato-15, BARI Tomato-16, Kosturi, Raja, Mintoo Super, Bipul Plus	BARI Tomato-2 (Ratan), Bahubali, BARI Tomato-9, BARI Tomato-15, BARI Tomato-14, Bipul Plus, Mintoo Super	BARI Tomato-7, BARI Tomato-8, BARI Tomato-9 (Lalima), BARI Tomato-10, Raja, Bahubali, Roma VF, Sofol, Mintoo Super, Bipul Plus,	BARI Tomato-2 (Ratan), BARI Tomato-8, BARI Tomato-9, BARI Tomato-10, Mintoo Super	BARI Tomato-2 (Ratan), BARI Hybrid Tomato-5. BARI Hybrid Tomato-6. Bipul Plus, Roma VF	BARI Tomato-2 (Ratan), BARI Hybrid Tomato-5, BARI BARI Tomato-14 BARI Tomato-16, BARI Tomato-18, Roma VF	Bahubali, Beauty plus, Bipul plus, BARI Tomato-2 (Ratan), BARI Hybrid Tomato-5. BARI Tomato-16, BARI Tomato-18 Pusa Ruby, Surakkha, Roma VF	Raja, Bahubali, Shiva, BARI Tomato-14 BARI Hybrid Tomato-5. BARI Tomato-16, BARI Tomato-18	Bahubali, BARI tomato-2, BARI Tomato-3, BARI tomato-14, BARI tomato-15, Marglobe, Roma VF	Bahubali, BARI Tomato-16, BARI Tomato-18, Raja, Bipul Plus

Table 4: Farmers' observations of major insect pests of tomato in the 20 surveyed upazilas (sub-districts) of Bangladesh

Insect Pests	Scientific Name	Family	Order	% Respondents in Different Study Areas										Mean	SD
				Dinajpur	Rangpur	Rajshahi	Bogura	Dhaka	Jashore	Barishal	Cumilla	Chittagong	Sylhet		
Harmful Insects															
Fruit Borer	*Helicoverpa* spp.	Noctuidae	Lepidoptera	100	100	100	100	100	100	100	100	100	98	99.80	0.63
Aphid	*Aphis* spp.	Aphididae	Homoptera	96	100	100	97	100	100	98	99	96	95	98.10	1.97
White fly	*Bemisia tabaci*	Aleyrodidae	Homoptera	98	99	100	100	98	97	99	96	95	92	97.40	2.50
Leaf miner	*Tuta absoluta*	Agromyzidae	Diptera	99	100	97	98	97	99	98	96	94	99	97.70	1.77
Thrips	*Thrips tabaci*	Thripidae	Thysanoptera	65	69	63	57	49	78	55	42	47	44	56.90	11.77
Beneficial Insects															
Ladybird Beetle	*Coccinella* spp.	Coccinellidae	Coleoptera	25	27	12	32	14	8	16	11	23	18	18.60	7.83
Syrphid fly	*Episyrphus balteatus*	Syrphidae	Diptera	9	12	6	15	7	5	13	17	11	14	10.90	4.04
Minute Pirate Bugs	*Orius insidiosus*	Anthocoridae	Hemiptera	7	9	6	10	8	5	12	8	6	3	7.40	2.59
Parasitic Wasps	*Bracon hebetor*	Braconidae	Hymenoptera	12	9	8	7	6	4	7	5	7	2	6.70	2.75

Key insect pests impacting tomato production

A variety of insect pests, as shown in Table 4, affected the tomato crops of the farmers who responded to the survey. Nearly all respondents in all upazilas said that the fruit borer (*Helicoverpa* spp.) was the most common pest (Table 4). Aphids (*A. gossypii* Glover), whiteflies (*B. tabaci* Genn.) and leaf miners (*T. absoluta* Mey.) were among the most frequently seen pests; infestations were reported by over 95% of farmers in the areas. Although there were notable geographical differences, thrips (*T. tabaci* Lind.) were less common, with only 56.9% of farmers reporting their presence (Table 4). 18.6% and 14% of farmers, respectively, reported seeing certain beneficial insects, such as ladybird beetles (*Coccinella* spp.) and syrphid flies (*Episyrphus balteatus* DeGeer). Although they were far less prevalent, farmers also reported seeing parasitic wasps (*Bracon hebetor* Say) and minute pirate bugs (*Orius* spp.) (Table 4).

Major tomato diseases

Table 5 lists the major diseases that farmers in the studied upazilas reported harming their tomato harvests. Tomato Yellow Leaf Curl Virus (TYLCV) was the most common, as reported by 94.2% of farmers (Table 5). There were also many reports of fungal diseases, such as early blight (*Alternaria solani* Ellis and G. Martin*)*) and late blight (*Phytophthora infestans* Bary), which affected 43.2% and 47.8% of farmers' fields, respectively (Table 5). Additionally, 30.80% of farmers said they had Fusarium wilt (*Fusarium oxysporum* Schlechter) and 43.40% said they had bacterial spot (*Xanthomonas campestris* Pammel) (Table 5). Although less common, root knot nematode disease was still substantial, as reported by 29.5% of farmers (Table 5).

Table 5: Farmers' perceptions of the major diseases of tomato in the 20 surveyed upazilas (sub-districts) of Bangladesh

Disease name	Causal organism	% Respondents in Different Study Areas										Mean	SD
		Dinajpur	Rangpur	Rajshahi	Bogura	Dhaka	Jashore	Barishal	Cumilla	Chittagong	Sylhet		
Viral Diseases													
Tomato Mosaic	*Tomato mosaic virus*	48	51	52	47	42	56	51	44	38	39	46.80	5.94
Tomato Yellow Leaf Curl	*Tomato yellow leaf curl virus*	94	93	95	96	95	99	97	96	92	85	94.20	3.79
Fungal Diseases													
Early Blight	*Alternaria solani* (fungus)	42	35	44	38	33	57	55	49	47	32	43.20	8.84
Late Blight	*Phytophthora infestans* (oomycete - fungus-like)	42	45	58	47	37	65	53	48	34	49	47.80	9.30
Fusarium Wilt	*Fusarium oxysporum* f. sp. *lycopersici*	15	19	24	35	54	45	47	24	31	14	30.80	14.08
Root Knot Nematode Disease	*Meloidogyne* spp.	18	15	29	35	38	32	37	36	29	26	29.50	7.91
Bacterial Spot	*Xanthomonas campestris* pv. *vesicatoria*	27	36	45	48	65	49	46	45	37	36	43.40	10.28

Table 6: Farmers' observations of major weeds of tomato in the 20 surveyed upazilas (sub-districts) of Bangladesh

Common name	Scientific Name	Family	Growth Habit	% Respondents in Different Study Areas										Mean	SD
				Dinajpur	Rangpur	Rajshahi	Bogura	Dhaka	Jashore	Barishal	Cumilla	Chittagong	Sylhet		
Bermuda Grass	*Cynodon dactylon*	Poaceae	Perennial Grass	88	85	90	87	89	84	82	81	86	80	85.2	3.2
Knotgrass	*Paspalum distichum*	Poaceae	Perennial Grass	80	78	79	76	77	74	72	70	73	69	74.80	3.6
Purple Nutsedge	*Cyperus rotundus*	Cyperaceae	Perennial Sedge	75	73	74	70	72	71	68	66	69	64	70.2	3.3
Barnyard Grass	*Echinochloa crus-galli*	Poaceae	Annual Grass	68	65	66	63	64	61	59	58	60	55	61.90	3.8
Broomrapes	*Orobanche* spp.	Orobanchaceae	Parasitic Weed	55	52	54	50	49	48	45	43	46	41	48.30	4.4

Major weeds in tomato fields

Survey results recorded that the most problematic weed was Bermuda grass (*Cynodon dactylon* Pers.). An average of 85.2% of farmers perceived it, with Rajshahi reporting the highest incidence at 90% and Sylhet reporting the lowest at 80%. The second most frequent weed was Knotgrass (*Paspalum distichum* L), which was reported by 74.8% of farmers and even slightly less in the southern districts, that is, Barishal and Cumilla. The percentage of tomato fields affected by purple nutsedge (*Cyperus rotundus* L.) was 70.2%, more in the north, for example, Dinajpur and Rangpur. The mean incidence of Barnyard grass (*Echinochloa crus-galli* L.) was 61.9%, Dinajpur being relatively higher, *i.e.*, 68% and Sylhet the least, *i.e.*, 55%. Broomrape was the least prevalent but still a problematic parasitic weed reported by 48.3% of average farmers, mainly in the northern districts, Dinajpur and Rajshahi (Table 6).

Frequently used pesticides

Various pesticides and fungicides were often employed by farmers, as shown in Table 7. The most often applied pesticides were neonicotinoids, such as Actara 25 WG (thiamethoxam) and Confidor 200 SL (imidacloprid). Amistar Top 325 SC (azoxystrobin + difenoconazole) and Ridomil Gold 68 WG (mancozeb + metalaxyl) were often used for fungal control (Table 6). Although several fungicides, such as Indofil M-45 (Mancozeb), were deemed unlikely to offer an acute hazard (Class U), the majority of the pesticides were classified as Class II (moderately hazardous) (Table 7).

Farmer's perspectives on yield reduction attributable to insect pests and diseases

Fig. 2 depicts the perspectives of farmers from 20 upazilas about yield loss in tomatoes attributable to insect pests (2a) and diseases (2b). The majority of farmers indicated yield loss of 30-39% attributable to insect pests (38.5%) and 40-49% attributable to diseases (37.25%). A considerable number of farmers encountered productivity losses of 40-49% attributable to insect pests (22.5%), while 23.5% of farmers indicated yield losses of 30-39% owing to diseases. The percentage of farmers indicating losses over 50% was modest, at 7.5% for insect pests and 21.0% for diseases, respectively.

Management techniques and frequency of pesticide utilization

Fig. 3a indicates that a predominant 78.5% of farmers used chemical approaches for the management of insect pests and diseases. Merely 3.5% of farmers used Integrated Pest Management (IPM), whereas 18% utilized a combination of chemical and non-chemical approaches. Fig. 3b illustrates the frequency of pesticide application, where 90.70% of farmers sprayed pesticides more than four times during the growing season. A minority of the group (8.05%) used pesticides four times, whereas just 1.25% of the farmers applied pesticides three times.

Interval of pesticide application and pre-harvest Interval (PHI)

As shown in Fig. 4a, the majority of farmers (52.0%) use pesticides at least once every seven days. While 3.5% used a

Table 7: List of commonly used pesticides in 20 tomato growing upazilas (sub-districts) of Bangladesh

Trade Name	Group Name	Common Name	Type	WHO Class
Confidor 200 SL	Neonicotinoids	Imidacloprid	Insecticide	II
Actara 25 WG	Neonicotinoids	Thiamethoxam	Insecticide	II
Admire 20 SL	Neonicotinoids	Imidacloprid	Insecticide	II
Nitro 505 EC	Organo Phosphate + Pyrethroids	Chlorpyrifos + Cypermethrin	Insecticide	II
Imitaf 20 SL	Neonicotinoids	Imidacloprid	Insecticide	II
Amistar Top 325 SC	Strobilurins + Triazole	Azoxystrobin + Difenoconazole	Fungicide	II
Virtako 40 WG	Diamides + Neonicotinoids	Chlorantraniliprole + Thiamethoxam	Insecticide	II
Ridomil Gold 68 WG	Phenylamide	Mancozeb + Metalaxyl	Fungicide	U
Antracol 70 WP	Dithiocarbamates	Propineb	Fungicide	U
Joymec 1.8 EC	Avermectins	Abamectin	Insecticide	II
Declare 2.5 EC	Pyrethroids	Deltamethrin	Insecticide	II
Shobicron 425 EC	Organo Phosphate + Pyrethroids	Profenofos Q+Cypermethrin	Insecticide	II
Goldazim 50 SC	Benzimidazole	Carbendazim	Fungicide	II
Karate 2.5 EC	Pyrethroids	Lambda-Cyhalothrin	Insecticide	II
Sumi Alpha 5 EC	Pyrethroids	Esfenvalerate	Insecticide	II
Regent 50 SC	Phenylpyrazole	Fipronil	Insecticide	II
Tilt 250 EC	Triazole	Propiconazole	Fungicide	II
Score 250 EC	Triazole	Difenoconazole	Fungicide	II
Folicur 250 EW	Triazole	Tebuconazole	Fungicide	III
Sevin 85 WP	Carbamates	Carbaryl	Insecticide	II
Success 2.5 SC	Spinosyns	Spinosad	Insecticide	U
Tracer 45 SC	Spinosyns	Spinosad	Insecticide	U
Indofil M-45 80 WP	Dithiocarbamates	Mancozeb	Fungicide	U
Dipel DF	Biological	Bacillus thuringiensis	Insecticide	U
Tafgor 40 EC	Organo Phosphates	Dimethoate	Insecticide	II
Morter 48 EC	Organo Phosphates	Chlorpyrifos	Insecticide	II

Ia = Extremely hazardous; Ib = Highly hazardous; II = Moderately hazardous; III = Slightly hazardous; U = Unlikely to present acute hazard; GHS = Globally Harmonized System of Classification and Labeling of Chemicals

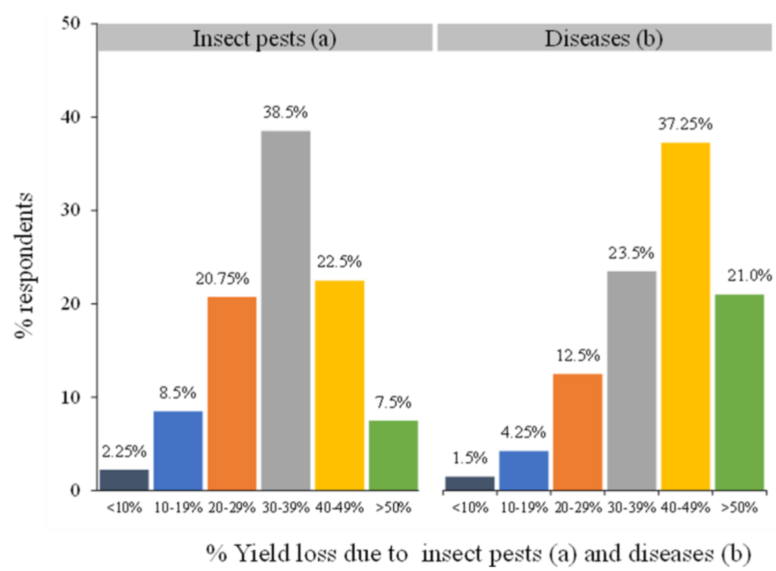

Fig. 2: Farmers' perceptions of yield loss of tomato due to insect pests (**a**) and diseases (**b**) of 20 surveyed upazilas (sub-districts) of Bangladesh

15-day gap, 35.5% used a 3-day interval. A significant proportion of farmers (9.0%) mentioned varying intervals. Fig. 4b displays the pre-harvest interval (PHI) recorded by farmers. It is worth noting that over half of the farmers (52.75%) waited two to three days after applying pesticides before harvesting. Around 25.50% followed a PHI for four to five days, while 15.25% followed a one-day PHI. While 1.25% waited more than 7 days, only 5.25% adhered to a PHI of 6–7 days.

Training on pest management

Fig. 5 highlights the status of training on pest management among the farmers. A substantial majority (71%) reported having received no training on pest management, while only 29% had undergone some form of training. This suggests a need for increased training initiatives to promote better pest management practices among tomato farmers.

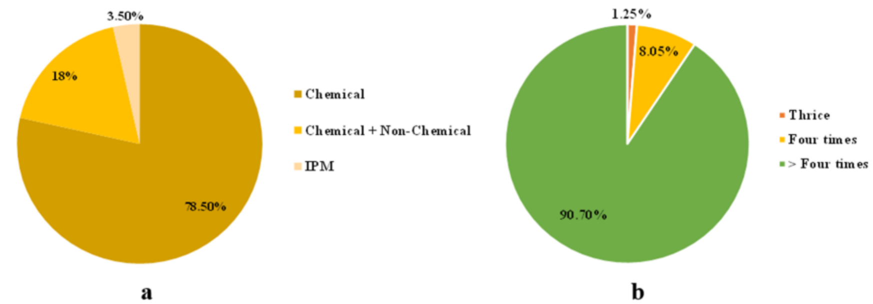

Fig. 3: (**a**) Management practices of insect pests and diseases by farmers; (**b**) Frequency of pesticide application to control insect pests and diseases of tomato in 20 surveyed upazilas (sub-districts) of Bangladesh

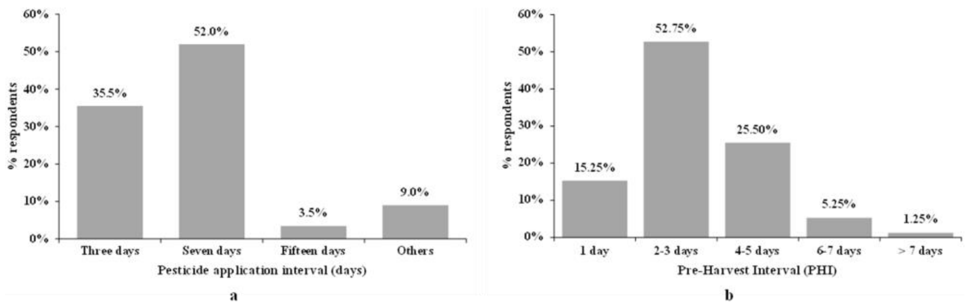

Fig. 4: (**a**) Interval of pesticide application for insect pests and disease control; (**b**) Pre-harvest interval (PHI) followed by farmers in 20 surveyed upazilas (sub-districts)

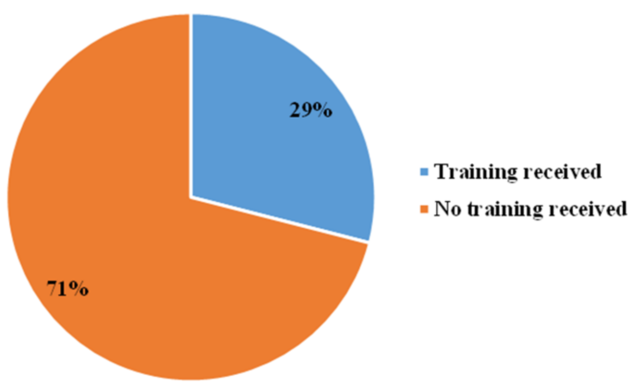

Fig. 5: Status of training on pest management among the tomato producing farmers of 20 surveyed upazilas (sub-districts)

Discussion

Socio-demographic status of tomato farmers

The socio-demographic data show that in Bangladesh, most tomato farmers are men and mostly middle-aged, which is similar to agricultural patterns in South Asia (Kabeer 2016). It is alarming that only 1.8% of farmers have a university degree. Higher education is known to improve farming productivity and encourage the adoption of new methods. Snilstveit *et al.* (2016) pointed out that farmers with more education tend to adopt better farming technologies. Since traditional methods are mostly used, there is an important need for specific education programs to fill the knowledge gaps and enhance farm output.

Farm size and tomato cultivation area

In Bangladesh, farm sizes are generally small, with the majority of the farms classified as small or marginal and the average farm size is 0.3 ha (or 0.75 acres) (Palash and Bauer 2017). Divided land makes it difficult to use technology and get cost-saving benefits (Hazell *et al.* 2010). When land is fragmented, it becomes hard to use machines and invest in costly farming supplies, which stops growth in making more crops (Ali *et al.* 2023). The World Bank (2007) found that in Bangladesh, small farmers often find it hard to get loans and farming supplies, which makes it tougher for them to grow and apply new farming methods. Ways to fix these issues could include working together on farms, getting small loans and having support from the government (Deininger and Byerlee 2011).

Tomato varieties grown in different upazilas

The utilization of both traditional and hybrid tomato varieties demonstrates a dependence on indigenous knowledge as well as contemporary agricultural methodologies. This finding aligns with the work of Pingali (2012), which emphasizes the significance of preserving varietal diversity to accommodate diverse local conditions. Improved varieties like BARI Tomato-16 and BARI Hybrid Tomato-5 are resistant to different diseases and can produce more fruit, which is important for increasing farm output, especially when pests are a problem. Local varieties demonstrate enhanced adaptability to specific micro-climates, a conclusion corroborated by Kontoleon *et al.* (2009), who highlight the significance of local varieties in sustaining biodiversity and resilience within agricultural systems. Policymakers and researchers must explore the development of hybrids that are tailored to specific regions, integrating local adaptability with enhanced resistance to pests and diseases.

Key insect pests impacting tomato production

The predominant pest identified in this research was the fruit borer (*Helicoverpa* spp.), reported by almost 100% of the questioned farmers. A recent study indicates that *Helicoverpa armigera* is one of the most destructive pests of tomatoes, attributed to its extensive host range and tolerance to many pesticides (Stavrakaki *et al.* 2024). Likewise, other pests, including aphids (*Aphis* spp.), whiteflies (*Bemisia tabaci* Genn.) and leaf miners (*Liriomyza* spp.), were identified by over 95% of farmers, all of which are extensively documented for their deleterious feeding behaviors and act as vectors of viral diseases, particularly in tropical and subtropical areas (Knapp *et al.* 2020; Abubakar *et al.* 2022).

Whiteflies present a significant concern due to their involvement in the transmission of Tomato Yellow Leaf Curl Virus (TYLCV), as observed in the current study. The ongoing problem with *Bemisia tabaci* (Genn.) as a major agricultural pest is due to its high ability to reproduce, wide variety of plants it can feed on and quick development of resistance to chemical insecticides (Horowitz and Ishaaya 2014). Thrips (*Thrips tabaci* Lindeman), while seen less often (56.9%), are important for spreading Tomato Spotted Wilt Virus (TSWV), which is still a big problem in places where they are found (Rotenberg *et al.* 2015). Only 18.6% of the surveyed farmers documented the occurrence of beneficial insects, specifically ladybird beetles (*Coccinella* spp.). This finding is consistent with previous studies indicating that extensive pesticide application frequently reduces the populations of natural predators, which are essential for effective integrated pest management (IPM) (Rusch *et al.* 2015; Pandey *et al.* 2022).

Major tomato diseases

The Tomato Yellow Leaf Curl Virus (TYLCV) represents the most prevalent disease, impacting 94.2% of agricultural fields surveyed. The virus, which is transmitted by whiteflies, represents a major threat to global tomato production. Research indicates that, if not managed effectively, it has the potential to result in complete crop loss in certain instances (Zhou 2013). The virus poses significant challenges in tropical and subtropical climates, environments that are conducive to the proliferation of whitefly populations (Barbosa *et al.* 2014). Fungal diseases, specifically late blight (*Phytophthora infestans* Bary) and early blight (*Alternaria solani* Ellis and Martin), were prevalent, impacting 47.8% and 43.2% of farmers' fields, respectively. These diseases are very common in wet areas, with *P. infestans* (Bary) known for causing quick and severe outbreaks when the weather is right (Fry *et al.* 2015). Early blight, although exhibiting lower aggressiveness, remains a persistent challenge in numerous tomato cultivation regions. The management of this disease is further complicated by the pathogen's capacity to endure in both plant debris and soil (Agtmaal *et al.* 2017).

Fusarium wilt, caused by *Fusarium oxysporum* (Schlechter), has been reported to affect 30.8% of agricultural fields. This disease presents a persistent challenge due to its soil-borne characteristics and the complexities associated with the eradication of the pathogen following its establishment. Recent studies show that changing the types of crops grown and using resistant varieties are the best ways to manage this disease (Michielse and Rep 2009). The bacterial spot disease, caused by *Xanthomonas campestris* (Pammel), affected 43.4% of tomato fields and is especially common in warm and humid areas that help bacteria grow (Adhikari *et al.* 2020). Root Knot Nematode Disease, despite its lower frequency of occurrence (29.5%), constitutes a significant concern due to its detrimental effects on the plant's root system, which in turn diminishes nutrient absorption (Kamran 2010).

Major weeds in tomato fields

The most prevalent weeds found in all the locations were Bermuda grass (*Cynodon dactylon* Pers.), which was reported to be present in more than 85% of farmers' fields. This plant causes harm mainly due to underground competition, which makes up 64% of the shoot dry weight falloff seen in tomato (Morales-Payan *et al.* 2003). This finding is consistent with a global trend in which *C. rotundus* L. is considered one of the most difficult and persistent weeds to control because its underground tubers allow propagation. Rajshahi had the highest prevalence (90%), which may be due to suitable soil conditions and irrigation of this region, which favored the growth of this fungus.

Bermuda grass (*Cynodon dactylon* Pers.), a C4 grass that grows widely from both rhizomes and stolons, plus by generating seeds (Noor *et al.* 2023). Commonly, fields under low weed management harbored this weed at a mean frequency of 74.8%. This rhizomatous perennial still poses a significant challenge to tomato fields. Dinajpur and Rangpur, where tomatoes grow in larger proportions, have an almost marginal point higher infestation.

Among the surveyed farms, observations of barnyard grass, a very common weed in moist and irrigated fields, were present in 85.2%. A significantly higher number of weeds, at 20, 40 and 80 weeds/m², will cause, respectively, 15%, 24% and 26% reductions in yield. At 160 and 320 weeds/m², weed biomass is larger than crop biomass by 8% and 30%, hence 36% and 39% reductions in yield, respectively. While the total yield is going down, the proportion of standard-quality fruit remains constant at 82-84% (Bairambekov *et al.* 2016).

On the other hand, Barnyard grass notwithstanding being less dominant than the first three already mentioned, was observed to pose difficulty for 61.9% of the farmers, especially those from Dinajpur and Rajshahi. This weed prefers waterlogged soils and is associated with poor field drainage.

Broomrapes (*Orobanche* spp.), a parasitic weed, were reported in 48.3% of the tomato fields. The weed species have caused an economic loss of USD 1.3–2.6 billion on solanaceous vegetables (Osipitan *et al.* 2021). It directly influences tomato plants, attaching itself to the roots and sapping the plants of their nutrients leads to stunting and loss of yields. Though it was not quite widespread, its occurrence in tomato fields calls for concern, especially on such a high scale in Dinajpur and Rajshahi districts.

Therefore, there is a high prevalence of these weeds and they must have integrated weed management practices of mulching, crop rotation and herbicide application to help reduce their impact on tomato production. The variation in weed prevalence between locations also implies implementing region-specific weed control measures for better management.

Frequently used pesticides

Farmers often used neonicotinoids, namely imidacloprid (Confidor 200 SL) and thiamethoxam (Actara 25 WG), for the management of insect pests. Neonicotinoids are extensively used because of their systemic properties and broad-spectrum effectiveness against sap-sucking pests such as aphids and whiteflies. However, using them a lot has been connected to fewer pollinators and some pests becoming resistant to them (Bass *et al.* 2015; Simon-Delso *et al.* 2015). Recent studies suggest that we need stricter rules and better pest control methods, like biological control and integrated pest management (IPM), to reduce the harmful effects of neonicotinoids (Wood and Goulson 2017). Farmers mostly used fungicides such as Azoxystrobin + Difenoconazole (Amistar Top 325 SC) and Mancozeb + Metalaxyl (Ridomil Gold 68 WG) for fungal control. These fungicides effectively manage a diverse array of fungal infections owing to their broad-spectrum efficacy (Ons *et al.* 2020). Using these compounds too much can lead to fungi becoming resistant to fungicides, which has happened with diseases like *Phytophthora infestans* (Tiwari *et al.* 2021). Mancozeb, classified as Class U (unlikely to provide acute hazard), is regarded as generally safe for human health risk; nonetheless, concerns have been expressed about its environmental persistence and possible long-term impacts (Huang *et al.* 2021). A significant number of pesticides used by farmers in this research are classified as WHO Class II (moderately hazardous), underscoring the need for safer options and appropriate safety practices during pesticide application. Research underscores the need to educate farmers on pesticide application and promote the use of Integrated Pest Management (IPM) strategies to diminish dependence on harmful pesticides while ensuring crop protection (Ali *et al.* 2020).

Farmers' assessment of yield reduction attributable to insect pests and diseases

Farmers in Bangladesh indicated substantial productivity reductions, with 30-39% attributed to insect pests (38.5% of respondents) and 40-49% attributable to diseases (37.25% of respondents). This finding corresponds with international research indicating that pests and illnesses significantly contribute to agricultural production reduction, especially in developing countries with subtropical temperatures (Oerke 2006). Significant losses (40-49%) were prevalent, with 22.5% of respondents attributing such decreases to insect pests, highlighting their pivotal impact on output reduction. Moreover, 21% of farmers reported yield losses above 50% owing to diseases, suggesting that severe diseases might inflict more catastrophic effects than insect pests (Savary *et al.* 2012). Studies indicate that ailments, such as bacterial wilt and fungal infections, flourish in humid tropical environments, hence intensifying these losses (Strange and Scott 2005; Bebber *et al.* 2014).

Management practices and pesticide application frequency

The majority of farmers (78.5%) relied on chemical pest control methods, which is consistent with findings from other developing countries where smallholder farmers have limited access to alternative pest management techniques (Popp *et al.* 2013). The low adoption of Integrated Pest Management (IPM) practices (3.5%) reflects similar challenges reported globally, where knowledge gaps and resource limitations prevent widespread IPM implementation (Pretty and Bharucha 2015). The frequent application of pesticides, with 90.7% of farmers applying them more than four times during the growing season, mirrors trends observed in regions with high pest pressures, where farmers apply pesticides as a precautionary measure rather than based on specific pest thresholds (Parsa *et al.* 2014).

Interval of pesticide application and pre-harvest interval (PHI)

A significant proportion of farmers indicated regular pesticide usage, with 52% administering pesticides every week and 35.5% doing so every three days. These short intervals are often linked to high pest problems in tropical regions and a lack of good tools to monitor them, forcing farmers to rely on frequent chemical treatments (Williamson *et al.* 2008). The pre-harvest interval (PHI) plays a vital role in minimizing pesticide residues on crops. However, data indicate that 15.25% of farmers harvested just one day after pesticide application, which raises significant food safety concerns (Aktar *et al.* 2009). This is consistent with the observations made by Alam *et al.* (2015) and Khatun *et al.* (2023), who documented comparable pesticide residue concerns in tomatoes from Bangladesh. In areas characterized by insufficient regulatory structures, compliance with suggested public health interventions frequently remains inadequate, resulting in possible health hazards (Tripathy *et al.* 2022).

Training on pest management

This study reveals a significant observation regarding pest management training, indicating that 71% of farmers have not received any formal instruction in this area. Not having enough training limits the use of sustainable methods, like integrated pest management, which has been shown to reduce pesticide use and improve crop yields in many studies (Parsa *et al.* 2014; Khan *et al.* 2021). Training and extension services are recognized as crucial for the dissemination of knowledge regarding safer and more effective pest management strategies (Zhang *et al.* 2011). Farmers who receive this training exhibit a higher propensity to implement non-chemical practices, thereby mitigating the environmental and health hazards linked to the excessive use of pesticides (Pretty and Bharucha 2015).

Conclusion

The study's results underscore the obstacles encountered by tomato growers in Bangladesh, attributed to insect pests and diseases that result in major yield losses and a need for regular chemical pesticide treatments. The inadequate knowledge and training of farmers in pest and disease control lead to actions that threaten food safety and environmental sustainability. The limited adoption of Integrated Pest Management (IPM) and the short pre-harvest intervals highlight the critical need for educational initiatives to enhance knowledge and promote sustainable practices. Creating accessible training programs and advocating for IPM methods are crucial measures for improving tomato yield and guaranteeing safer products. By focusing on these essential areas, policymakers and agricultural stakeholders may facilitate the transition to more resilient and sustainable tomato-producing systems in Bangladesh, therefore enhancing farmers' livelihoods and food security.

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Author Contribution

MEH did the whole research, as well as data collection and analysis, during the post-graduate program under the supervision of MMR. MSH, AA, MKH and JA helped in conceptualization. MSIK was involved in the preparation of the manuscript. RA and SH helped to revise the manuscript.

Conflict of Interest

No conflict of interest exists, according to the author.

Data Availability

Data presented in this study will be available on a fair request to the corresponding author.

Ethics Approval

Not applicable to this paper.

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