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Survey on the health of potato seeds and potato crops in Northwest Syria reveals first findings of non-indigenous potato pathogens, *Geotrichum candidum* (causal organism of Rubbery Rot) and *Macrophomina phaseolina* (causal organism of Charcoal Rot)

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Abstract Potato is an important food crop in Syria, particularly during the current crisis. Healthy seed stocks are vital in maintaining yields and quality, but the crop health risks associated with imported and home-multiplied seed are unknown. Between 2020–2022 pathogens in locally multiplied seed (LMS), and imported seed potatoes (ISP) and open fields grown from these sources were surveyed. Seed tubers from LMS and ISP were assessed using mass spectrometry (MOLDI-TOF MS). There was a greater prevalence of pathogens in LMS, although some important potato pathogens were also detected on ISP. On LMS seven fungal pathogens were detected, including *Geotrichum candidum* (causal organism of rubbery rot) on 35% of the samples and *Macrophomina phaseolina* (causal organism of charcoal rot disease) on 17% of the samples. These are first reports of these pathogens in Syria. On ISP four fungal pathogens were detected in 2022. The incidence of the detections was lower on IPS, although disease severity was similar to those found on LMS. Quarantine pathogens were not detected in either source. Field diseases assessments in northwest Syria showed a high prevalence of disease symptoms in crops grown from LMS. In crops grown from ISP disease levels were much lower, however results may be confounded by the fact that crops grown from ISP were surveyed in a spring growing season, and the crops raised from LMS were surveyed in autumn growing seasons. Nevertheless, the research highlights the lower health status of LMS.

Keywords Potato · *Geotrichum candidum* · *Macrophomina phaseolina* · Seed borne disease

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Introduction

Globally, the potato crop is the fourth most important food crop after wheat, rice, and corn with a total world production estimated at 470.5 million tonnes in 2021 (FAO, 2022).

Before the conflict in Syria, potato production was 720 thousand tonnes in 2008, but it was severely reduced to 441 thousand tonnes in 2014 (FAO, 2022). Since then, production has increased but remains at approximately two-thirds of pre-crisis levels (FAO, 2018- Special Report). However, the annual production of potatoes in Syria cannot be accurately estimated due to ongoing conflict in the country since 2011. Most potato cultivars are susceptible to multiple fungal, viral and bacterial diseases, which affect both the quality and quantity of potato production. The severity of potato losses due to disease is classified as semi-intensive for both quality and quantity (Savary et al., 2012).

Northwest Syria is considered one of the main areas for potato production and multiplication of seed stocks in the country. A large number of potato cultivars are produced to satisfy different requirements, such as processing and home consumption.

Globally, it has been estimated that approximately 22% of potato crops are lost annually due to viral, bacterial, fungal, and pest attack on potato tubers and plants, incurring an annual losses of over 65 million tonnes (Czajkowski 2011). Bacterial potato diseases can play a decisive role in the cultivation of this crop (Guchi et al., 2015). The most damaging bacterial pathogens listed as quarantine pathogens, include bacterial ring rot *Clavibacter michiganensis* subsp. *sepedonicus* (causal organism of bacterial ring rot), and *Ralstonia solanacearum* (causal organism of bacterial wilt or brown rot). Both are highly destructive and difficult to control once established in a production system (European Union, 2022). Because they are not present in all areas where potatoes are grown, strict quarantine measures should be applied to prevent their spread (Wilson et al., 2001). Additionally, soft rot diseases caused by *Pectobacterium carotovora* subsp *carotovora*, *P. carotovora* subsp. *atrospectica* and *P. chrysanthemi* can cause significant damage in field and during storage (Campos & Ortiz, 2020; Rahman et al., 2012). These bacterial diseases are considered very critical for potato production, as they can seriously affect the yield and quality of the potato crops. Fungal diseases, such as dry wilt, Fusarium wilt and Verticillium wilt (Rupp & Jacobsen, 2017) can also have a detrimental effect on crop production.

In Syria, very few data have been published since 2012. The fungi *Colletotrichum coccodes*, the causal pathogen of black dot disease on potato, was isolated and identified by Matar et al. (2012), in a specific field survey conducted in central and northern Syria. The common scab bacterial disease (*Streptomyces scabies*) was investigated by Taweel et al. (2013), and several potato cultivars were evaluated for succeptibility in the IDLIB governorate. Similar work on bacterial soft rot was carried out by Nabhan et al. (2009). However, there has been no comperhensive survey of bacterial and fungal disease in over a decade.

Healthy seed stock is vital for maintaining yields and quality, but the crop health risks associated with imported and home-multiplied seed after the Syrian crisis are now uncertain. It is possible for trained inspectors to visually observe some seed health attributes (e.g. disease symptoms), but the absence of latent infections and some symptomless viruses can only be ensured through laboratory testing. Thus, it is difficult to have confidence in the quality and source of seed sold in local markets. This seed is often of unknown health and may harbour seed-borne diseases that reduce yields (McEwan, 2021).

Due to the lack of an effective agricultural quarantine system in northern Syria and ineffective Turkish/Syrian border control since 2012, there is a considerable risk that new pathogens could be brought into Syria on non-certified or low-quality seed materials. Since 2012, there has been no survey of the disease risks within this region of Syria. As many of these diseases do not have effective chemical control measures, it is even more essential that they are not imported into a region where the rural economy has been weakened by years of conflict. This project aimed to survey imported and local seed potato sources and advise on strategies that would reduce risks going forward.

Material and methods

This investigation of the health status of seed potato and growing crops was conducted in eight separate locations of the Aleppo Governorate in Northwest

Syria (NWS), (Fig. 1) during the spring and autumn growing seasons of 2020–2022. The ongoing security situation in this region sometimes restricted the ability to access samples.

The survey was divided into two separate phases (a) An assessment of the presence of fungal and bacterial contamination on seed potatoes: both those imported from EU counties into the region of NWS as certified seed, and those informally multiplied by farmers within the region. (b) A survey of the field health of commercially grown potato crops and interviews with potato growers.

Seed potato sampling

During August 2020 and again in August 2022, growers with locally multiplied seed potatoes (LMS) lots (around one metric tonne each) which were due to be planted during the autumn production season were sampled. At each location 100 tubers per lot of seed tubers were randomly selected. Ten LMS samples were collected during August 2020 and a further seven samples in 2022. Imported (Elite class-EU grade) seed potatoes (ISP) were also sampled during January 2021 (nine samples) and again in January 2022 (eight samples) prior to planting for the spring production season. Samples were chosen to ensure a mix of cultivars, countries of origin, and regions of the Aleppo Governorate. At each location the sampled seed tubers were placed into new paper sacks and placed into a cooled ice box for transportation to the testing laboratory.

Isolation and identification bacterial and fungal pathogens

On arrival at Hatay Mustafa Kemal University (HMKU) plant clinic, samples were stored for a maximum of 3 weeks at 4 °C until further use. Fifteen asymptomatic potato tubers were subsequently

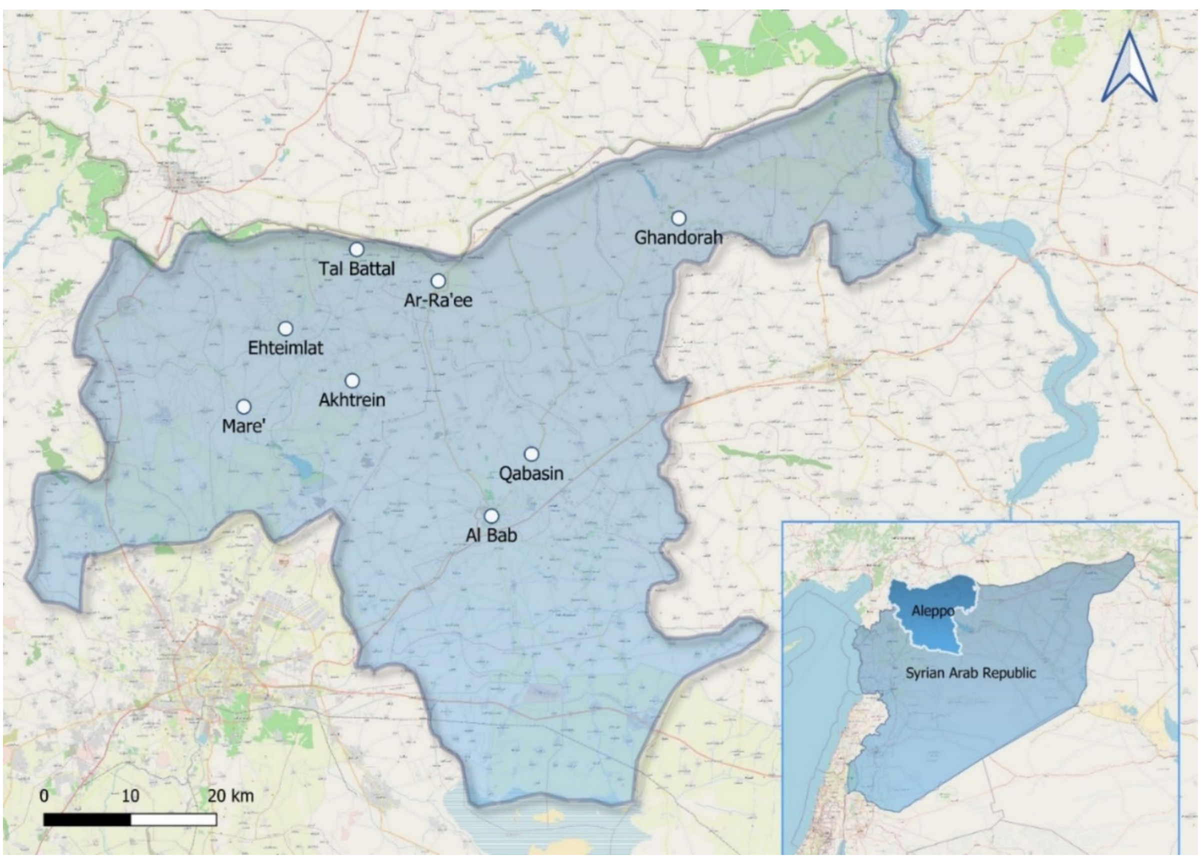

Fig. 1 Surveyed locations in Aleppo Governorate in Northwest Syria 2020–2022

selected from each 100 tuber sample and peeled and cut longitudinally.

For fungal isolation, small parts of both skin and tuber cortex were cultivated in Petri dishes on solid Potato Dextrose Agar (PDA) and incubated at 22 °C for 3 to 5 days (Thuillier et al., 2016). For bacteria isolation, homogenised skin and cortex tissue were streaked onto nutrient agar (NA) media and incubated at 27 °C for 24 h (Haj Hamed, 2008).

Identification of bacterial and fungal isolates was conducted using matrix-assisted laser desorption ionization time-of-flight mass spectrometry (MALDI-TOF MS) fingerprinting analysis (Ziegler et al., 2012 and Stets et al., 2013). This device detects and identifies microbes based on proteomic molecular weight, based on their flight time to reach a sensitive detection service which allows the accurate identification of microbes by comparing with global microbial databases. The amount of each fungus or bacteria identified in each sample was expressed on a scale from 1–6 as a quantitative criterion for the amount present in the sample according to the Plant Health Clinic protocol laboratories of Hatay Mustafa Kemal University, where: 1 = Very low level (less than 20% of presence of bacteria or fungi); 2 = Low (between 20 and 40%); 3 = Medium (40–60%); 4 = High (60–80%); 5 = Very high (80–90%); 6 = Extremely high (more than 90%). In January 2021, only bacterial microbes were isolated and identified.

Field disease survey and assessment

In both autumn (2020 & 2022) and spring production seasons (2021 & 2022), a total of 163 fields were inspected in eight different locations of the NWS (Fig. 1).

At each location the crop was initially inspected by flying a drone (DJI C5 Mini 2 from SZ DJI Technology Co Ltd company) to observe all areas of the crop. The flight path was controlled by the operator and permitted real time observation of all areas of the crop. Areas of the field where crop growth was less vigorous were identified and these areas were subject to further direct scrutiny. At each selected location, pictures were taken of symptoms present on different plant parts and a minimum of five plants were dug, underground parts examined, and photographed as appropriate. Photos were examined by all team members to provide an agreed diagnosis based on the visual symptoms. Disease identification was based on the guides of the United Nations (2014) and the International Potato Center (2018).

Each field was inspected at least twice during the growing season at different growth stages, starting from three weeks after emergence and included; rapid canopy formation, flowering, and pre-harvesting stages to assess the presence of diseases.

The percentage area of each field containing infected plants of each disease was estimated during the drone and in person inspections, expressed as Percentage of Infection Area (PIA). This figure provided an indication of disease severity.

Grower survey

Following ethical approval from Cara Ethics Committee 2020 and consent from potato farmers, they were interviewed to provide confidential information on their personal circumstances (age, experience, education) and specific information relating to their potato crops, such as fertilizer source, pesticide usage, irrigation applied and methodology, yield expectation, production challenges and the availability of agriculture extension. Interviews were conducted face to face with data entered directly into a Kobo toolbox software via a smart phone.

Results

Input seed potato sanitation

(a) Isolation of bacteria and fungi from locally multiplied seed (LMS):

The results (Tables 1 and 2) showed that both bacteria and fungi were detected in all samples with contamination levels ranging from very low (1) to very high (5). A wide range of different bacterial species where detected in all samples of LMS, although none are recognized as potato pathogens. The highest levels of bacterial contamination were found in cv. Spunta and Synergy contaminated with *Pseudomonas koreensis*, and *Pseudomonas kilonensis* respectively. The most frequently detected bacterial species in 2020 was *Erwinia herbicola* (4

Table 1 Bacterial and fungal contamination and infection levels of locally multiplied seed (LMS) in NW Syria in 2020 using MOLDI-TOF

Cultivar	"Microbe Type"	Microbe name	Contamination level**
AL bayda	Fungi	*Alternaria alternata**	1
	Fungi	*Macrophomina phaseolina**	1
	Bacteria	*Enterobacter kobei*	3
	Bacteria	*Erwinia herbicola*	4
	Fungi	*Geotrichum candidum**	4
Arizona	Fungi	*Macrophomina phaseolina**	1
	Bacteria	*Pseudomonas sp.*	2
	Bacteria	*Xanthomonas hortorum*	2
	Bacteria	*Erwinia herbicola*	2
	Bacteria	*Pantoea agglomerans*	2
	Fungi	*Alternaria alternata**	2
	Fungi	*Fusarium solani**	2
	Fungi	*Fusarium oxysporum**	3
	Fungi	*Colletotrichum coccodes**	5
Binella	Bacteria	*Glutamicibacter arilaitensis*	2
	Fungi	*Fusarium sambucinum**	3
Cephora	Fungi	*Alternaria alternata**	3
	Bacteria	*Pseudomonas koreensis*	4
	Fungi	*Geotrichum candidum**	5
Fabula	Bacteria	*Pseudomonas thivervalensis*	2
	Fungi	*Alternaria alternata**	2
	Bacteria	*Pseudomonas kilonensis*	3
	Fungi	*Geotrichum candidum**	3
La Strada	Bacteria	*Pseudomonas mediterranea*	3
	Bacteria	*Pseudomonas koreensis*	3
	Fungi	*Alternaria alternata**	3
	Fungi	*Fusarium oxysporum**	3
Montreal	Bacteria	*Pseudomonas syringae*	2
	Bacteria	*Pseudomonas caricapapayae*	3
	Fungi	*Geotrichum candidum**	3
Sylvana	Bacteria	*Erwinia herbicola*	2
	Fungi	*Fusarium oxysporum**	3
	Bacteria	*Pseudomonas gessardii*	4
	Fungi	*Geotrichum candidum**	4
Spunta	Fungi	*Fusarium oxysporum**	2
	Fungi	*Fusarium sambucinum**	2
	Bacteria	*Pseudomonas koreensis*	5
Synergy	Fungi	*Fusarium acuminatum**	1
	Bacteria	*Acinetobacter calcoaceticus*	3
	Bacteria	*Pseudomonas thivervalensis*	3
	Fungi	*Geotrichum candidum**	3
	Fungi	*Fusarium sambucinum**	3
	Bacteria	*Erwinia herbicola*	4
	Fungi	*Fusarium oxysporum**	4
	Bacteria	*Pseudomonas kilonensis*	5

(*) Potato pathogen

(**) a quantitative criterion for the amount of the microbe present in the sample; where: 1 = Very low level (less than 20% of presence of bacteria); 2 = Low (between 20 and 40%); 3 = Medium(40–60%); 4 = Hight(60–80%); 5 = Very high (80–90%); 6 = Extremely high (more than 90%)

Table 2 Bacterial and fungal contamination and infection levels of locally multiplied seed (LMS) in NW Syria in 2022 using MOLDI-TOF

Cultivar	"Microbe Type"	Microbe name	Contamination level**
Alegira	Bacteria	*Bacillus megaterium*	3
	Bacteria	*Bacillus mojavensis*	2
	Fungi	*Alternaria* spp.*	3
	Fungi	*Macrophomina phaseolina**	3
	Fungi	*Colletotrichum coccodes**	3
	Bacteria	*Bacillus subtilis*	3
	Fungi	*Fusarium* spp.*	3
Arizona	Bacteria	*Bacillus simplex*	2
	Bacteria	*Pseudomonas korensis*	3
	Fungi	*Alternaria* spp.*	2
	Bacteria	*Bacillus subtilis*	3
	Fungi	*Fusarium* spp.*	2
	Fungi	*Penicillium* spp.	2
La strada	Bacteria	*Bacillus simplex*	2
	Bacteria	*Pseudomonas thivervalensis*	3
	Fungi	*Fusarium solani**	4
Monterial	Bacteria	*Bacillus megaterium*	4
	Fungi	*Fusarium solani**	2
	Fungi	*Colletotrichum coccodes**	4
Safiyah	Fungi	*Fusarium* spp.*	3
	Fungi	*Alternaria* spp.*	3
Sylvana	Bacteria	*Bacillus megaterium*	2
	Fungi	*Colletotrichum coccodes**	4
	Fungi	*Fusarium oxysporum**	1
	Fungi	*Macrophomina phaseolina**	2
Synergy	Bacteria	*Bacillus megaterium*	2
	Fungi	*Fusarium solani**	2
	Fungi	*Fusarium* spp.*	3

(*) Potato pathogen

(**) a quantitative criterion for the amount of the microbe present in the sample; where: 1 = Very low level (less than 20% of presence of bacteria); 2 = Low (between 20 and 40%); 3 = Medium(40–60%); 4 = Hight(60–80%); 5 = Very high (80–90%); 6 = Extremely high (more than 90%)

samples), but this bacteria was not detected in 2022. However, *Bacillus megaterium,* the most common species (4 samples) detected in 2022, was absent from all samples in 2020.

In contrast, with the single exception of a single isolation of *Penicillium* spp, all of the fungal species detected were species or genera of recognized potato pathogens. Fungal pathogens were detected in all tested samples and in several instances more than one species was detected. *Fusarium* species were found in the majority of samples (9 out of 12 samples) with 17 isolations of a range of species (*F. oxysporium*, *F. sambucinum, F. acuminatum, F. solani,* and 2 samples identified to genus level as *Fusarium* spp.). *Fusarium* species were all detected with contamination level of 3 or less, with the exception of a single sample (cv. Synergy, 2020) of *F.oxysporium* which reached level 4. *Alternaria alternata* and other samples only identified to genus level as *Alternaria* spp. were also detected frequently (8 of 17 samples), with contamination level from 1 to 3.

Less frequently the pathogen species include *Geotrichum candidum,* which was detected in 6 samples, all taken during the 2020 season (Fig. 2), and *Macrophomina phaseolina* was detected in 4 samples, two were during the 2020 and two in 2022. *Colletotrichum coccodes* was detected on four samples at higher levels of contamination (3 to 5) over both 2020 and 2022.

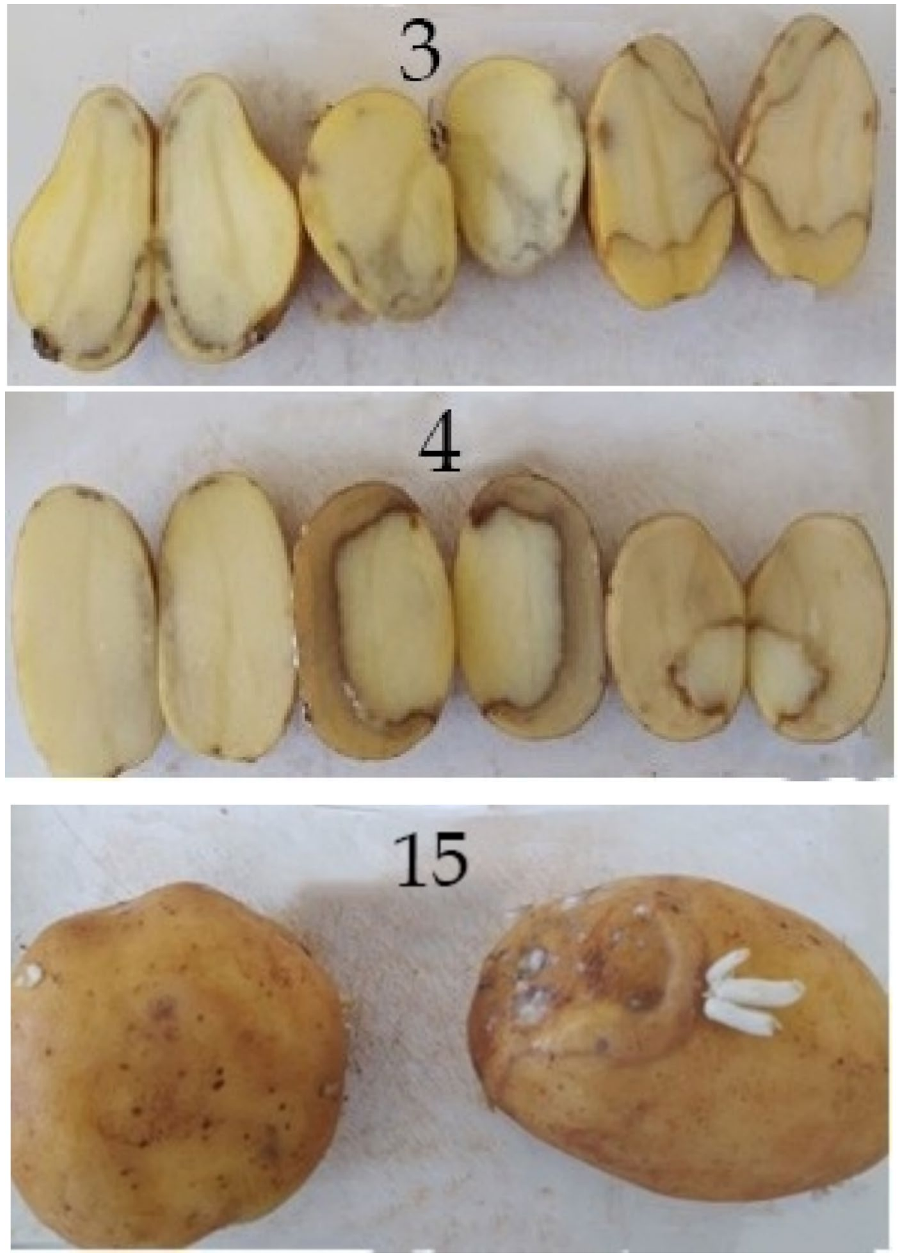

Fig. 2 Symptoms of *Geotrichum candidum* the causal agent of rubbery rot disease on potato during autumn 2020 – LMS, in Montreal (3) AL bayda (4) and Sylvana (15) Cultivar observed in ALBAB location, detected for the first time in North Syria

(b) Isolation of bacteria and fungi from imported potato seed (ISP)

In 2021 the testing was restricted to bacterial species (Table 3). However, in 2022 both bacterial and fungal species were included in the testing regime (Table 4). In 2021 across the 9 samples tested, 16 different species of bacteria were identified. No species could be considered dominant and none are recognized as potato pathogens. In 2022, the results are similar with a wide range of non pathogenic bacterial species detected. In 2022, a number of recognized fungal potato pathogens were detected. The most frequently isolated pathogens were *Alternaria* spp.(4 samples), *Colletotrichum coccodes* (4 samples) and *Fusarium* spp. (3 samples). Of these most were detected at level 3 or less with the exception of *Colletotrichum coccodes*

Table 3 Microbe contamination and infection levels of Imported potato seed (ISP): in NW Syria in 2021 using MOLDI-TOF

Cultivar	Country of origin	Microbe name	Contamination level**
Binella	Netherlands	*Pseudomonas libanensis*	2
La strada	Scotland	*Staphylococcus succinus*	3
Synergy	France	*Pseudomonas rhodesiae*	4
		Pantoea agglomerans	5
		Pseudomonas corrugate	3
		Pseudomonas thivervalensis	2
Arizona	Netherlands	*Erwinia herbicola*	4
		Pseudomonas poae	3
		Xanthomonas hortorum	3
		Pseudomonas synxantha	2
		Pseudomonas libanensis	3
Sylvana	Austria	*Stenotrophomonas rhizophila*	5
		Paenibacillus amylolyticus	3
Fabula	Netherlands	*Erwinia herbicola*	5
		Pantoea agglomerans	1
		Paenibacillus amylolyticus	4
Sababa	Netherlands	*Bacillus atrophaeus*	4
Sagitta	Netherlands	*Staphylococcus* sp.	2

(*) Potato pathogen

(**) a quantitative criterion for the amount of the microbe present in the sample; where: 1 = Very low level (less than 20% of presence of bacteria); 2 = Low (between 20 and 40%); 3 = Medium(40–60%); 4 = Hight(60–80%); 5 = Very high (80–90%); 6 = Extremely high (more than 90%)

which was consistently detected at higher levels (4 or 5).

Field diseases assessments

163 accessible potato fields in eight different locations of Northwest Syria were surveyed for the presence of diseases (Fig. 1): 67 fields in the autumn 2020, 51 in autumn 2021 and 45 in spring 2022. This survey included 15 cultivars across the different locations of NWS. All spring produced potato fields (45) were grown from ISP and all autumn potato fields (118) were grown from LMS. The most commonly cultivated cultivars were Binella (39 fields), Arizona (35 fields), Synergy (19 fields) and La-strada (17 fields) (Table 5).

However in autumn potato feilds produced using LMS a wider range of diseases were observed at a higher frequency. The most frequent diseases observed were late blight (24% of fields) and stem canker (*Rhizoctonia solani*, 19% of fields). Potato blackleg (generic symptoms so multiple possible causal organisms including *Pectobacterium* spp *and P. chrysanthemi*, 7%), common scab (*Streptomyces* spp, 9%), early blight (2%) and potato leaf roll virus (7%) were also observed in crops. With the exception of both early and late blight, these diseases were not observed during the spring season (Table 5).

Regarding the Percentage of Infection Area (PIA) rate in all infected surveyed fields, the results showed that the highest (PIA) were 53%, 46%, and 38% of surveyed fields planted with LMS were infected with common scab (Fig. 3), stem canker and late blight respectively. Meanwhile, it was 18% in blackleg and 16% in leaf roll disease. On the other hand, in the field planted with ISP, it was only 23% and 20% in late blight and early blight respectively (Table 6).

Grower survey

The results of surveyed potato farmers during 2020 and 2022 showed considerable diversity of the age groups of potato growers, where the knowledge of young people was mixed with the experiences of the elderly. More than half (56%) of the potato farmers were between 20–40 years, while 44% were 40–60 years. The area of potatoes being grown ranged from 0.5 to 8.0 ha (average 2.8 ha). All interviewed potato growers were using a range

Table 4 Microbe contamination and infection levels of Imported potato seed (ISP): in NW Syria in 2022 using MOLDI-TOF

Cultivar	Origin country	"Microbe Type"	Microbe name	Contamination level**
Alegira	Germany	Bacteria	*Enterobacter cloacae*	5
		Fungi	*Alternaria alternata**	3
		Fungi	*Fusarium oxysporum**	2
Arizona	Netherlands	Bacteria	*Bacillus pumilus*	3
		Bacteria	*Pseudomonas kilonensis*	3
		Fungi	*Colletotrichum coccodes**	4
		Bacteria	*Staphylococcus succinus*	3
		Fungi	*Alternaria alternata**	4
La strada	Scotland	Bacteria	*Enterobacter cloacae*	3
		Bacteria	*Pseudomonas thivervalensis*	2
		Fungi	*Fusarium solani**	2
		Fungi	*Penicillium sp.*	3
Montreal	France	Bacteria	*Pseudomonas thivervalensis*	4
		Fungi	*Colletotrichum coccodes**	5
Safiyah	UK	Bacteria	*Bacillus simplex*	3
		Fungi	*Alternaria alternata**	4
		Fungi	*Colletotrichum coccodes**	4
Sylvana	Austria	Bacteria	*Bacillus simplex*	5
		Bacteria	*Bacillus muralis*	3
		Fungi	*Colletotrichum coccodes**	5
Synergy	France	Bacteria	*Pseudomonas caricapapayae*	3
		Bacteria	*Bacillus pumilus*	2
		Fungi	*Fusarium oxysporum**	3
		Fungi	*Alternaria alternata**	3

(*) Potato pathogen

(**) a quantitative criterion for the amount of the microbe present in the sample; where: 1 = Very low level (less than 20% of presence of bacteria); 2 = Low (between 20 and 40%); 3 = Medium(40–60%); 4 = Hight(60–80%); 5 = Very high (80–90%); 6 = Extremely high (more than 90%)

of inorganic and organic fertilisers, sprinkler irrigation, and chemical pesticides to control pests and diseases without any other alternative methods such as biological control.

The interviews showed that the potato growers were facing many challenges related to cultivation of potato crop, especially for obtaining high-quality seed from a reliable source, due to their poor purchasing power and the high prices of imported seed potatoes. Moreover, the interviews highlighted, the absence of local government institutions able to supervise the import of seed potatoes and facilitate access to the seed market, and providing education and extension services presenting further challenges to the production of a high input cost crop. The growers indicated that there had been a noticeable decline in potato crop cultivation in NWS since 2011.

Discussion

It is clear that the potato crop contributes significantly to local food security in Syria. However, the recent and ongoing political situation has adversely affected potato production as costs have increased and the availability of inputs such as certified seed potatoes has been restricted (Mohamad et al., 2021). This survey, is the first formalized study of potato disease incidence in NWS since 2012 and has highlighted significant plant health issues. Previous studies highlighted the presence of *Colletotrichum coccodes*, the causal pathogen of black dot disease. Matar et al. (2012) and Taweel et al. (2013) tested several potato cultivars agaist the common scab disease caused by *Streptomyces scabies* in IDLIB governorate, and similar work on bacterial soft rot was reported by Nabhan et al. (2009).

Table 5 The number of infected open potato fields and type of diagnostic diseases in each potato cultivars according to seed source in NWS

Cultivar		# of field infected in each disease														Total infected fields
		ISP (Spring)					LMS (Autumn)									
		Infected fields			Healthy	*Total fields*	Infected fields							Healthy	*Total fields*	
		Early blight	Late blight	Total infected fields			Black leg	common scab	Early blight	Late blight	Stem Canker	leaf roll	Total infected fields			
1	Alegria	1	0	***1***	5	***6***	-	-	-	-	-	-	-	-	-	***1***
2	El Mundo	-	-	-	-	-	1	0	0	1	1	0	**3**	1	***4***	***3***
3	Arizona	0	1	***1***	11	***12***	2	0	1	5	2	1	**11**	12	***23***	***12***
4	Binella	-	-	-	-	-	0	8	1	9	12	2	**32**	7	***39***	***32***
5	Fabulla	-	-	-	-	-	-	-	-	-	-	-	-	-	***1***	***1***
6	Kazil	-	-	-	-	-	0	0	0	0	1	0	**1**	0	***1***	***1***
7	La strada	0	1	***1***	2	***3***	0	1	0	3	1	1	**6**	8	***14***	***7***
8	Mazyca	-	-	-		-	1	1	0	2	2	1	**7**	0	***7***	***7***
9	Montreal	0	1	***1***	5	***6***	1	0	0	2	1	0	**4**	1	***5***	***5***
10	Sababa	0	0	**0**	3	***3***	0	0	0	1	0	0	**1**	2	***3***	***1***
11	Safiyah	0	0	**0**	3	***3***	-	-	-	-	-	-	-	-	-	***0***
12	Spunta	-	-	-	-	-	0	0	0	1	0	1	**2**	1	***3***	***2***
13	Sylvana	0	0	**0**	9	***9***	-	-	-	-	-	-	-	-	-	-
14	Synergy	0	0	**0**	3	***3***	2	1	0	4	2	2	**11**	5	***16***	***11***
15	Syphora	-	-	-	-	-	0	0	0	1	1	0	**2**	0	***2***	***2***
Total		***1***	***3***	***4***	***41***	***45***	***7***	***11***	***2***	***29***	***23***	***8***	**80**	***38***	***118***	***84***

(-) No planted cultivar

Fig. 3 Typical symptoms of common scab disease in autumn 2021- LMS (Binella Cultivar observed in ARr'ee location)

This study therefore sets out a baseline position on the incidence and severity of potatoe diseases in the NWS, ten years after the the crisis.

The results showed that the samples of both LMS and ISP were contaminated by many species of bacteria including; *Erwinia herbicola, Xanthomonas hortorum, Pseudomonas syringae* and *Pantoea agglomerans.* These are considered as opportunistic plant pathogens of a range of crops (Werraet al., 2020). Tsror et al. (1999) reported a similar range of bacterial species on domestically produced and imported seed potatoes in Palestine.

Syria is considered to be free from the quarantine pathogenic bacteria, *Clavibacter michiganensis* subsp. *Sepedonicus* (the causal agent of potato ring rot) and *Ralstonia solanacearum* (brown rot) (Syrian Ministry of Agriculture, 2011). Encouragingly, these were not detected in this survey of both imported and locally multiplied seed potatoes, although this finding is caveated by the small size of the survey and the fact that both pathogens can be hard to isolate into visible colonies. However the MALDI-TOF MS is able to detect them so it is probable that they were not present in this survey. *Pectobacterium* spp. were also not detected in any samples of seed potato tubers pre planting. However, blackleg disease symptomes, caused primarily by *Pectobacterium atroseptica* was observed in crops produced from LMS.

Table 6 Potato percentage of infection area (PIA) for each disease according to the seed source and growing season

Disease name	Potato seed source	
	ISP (Spring)	LMS (Autumn)
Black leg	-	18%
Common scab	-	53%
Early blight	20%	30%
Late blight	23%	38%
Leaf roll	-	16%
Stem canker	-	46%

The study showed that the imported potato seeds were contaminated with *Erwinia herbicola*, which is considered one of the species that infects horticultural plants and reported to be associated with spoilage (Umezuruike et al., 2019). This result also agreed and overlaped with a study conducted in Bangladesh by Rahman et al. (2012).

The most frequently isolated genera of fungal pathogen detected were *Fusarium* species. *F. oxysporium and F. solani and, F. sambucinum* were detected in both ISP and LMS seed. However*, F. acuminatum,* was only detected in LMS seed. Both *F. sambucinum* and *F. acuminatum* have not previously been reported from this region. Altinawi & Faddoul (2023) identified a subspecies of *F. oxysporium f.* sp. *Tuberosi* as present in the central and coastal areas of Syria causing vascular wilt and dry rot on tuber and plant over two seasons, 2018 and 2019 demonstrating the potential for these pathogens to cause yield loss in the field and during storage. *Fusarium* spp. are not considered to be quarantine pests. However, import conditions state that tubers should be inspected before importation and rejected if the disease is present (Syrian Ministry of Agriculture, 2011).

Importantly, this study also detected the presence of both *Geotrichum candidum,* the causal agent of rubbery rot and *Macrophomina phaseolina,* the causal agent of charcoal rot on multiple samples of locally multiplied seed. This is the first report of these species on potatoes in North Syria. These are reported as the causal agent of rubbery rot on potato in Konya Province, Turkey (Soylu et al., 2021), and in Michigan, USA (Willbur, 2023), and charcoal rot in potato in Mauritius (Takooree et al., 2021) respectively. *Geotrichum candidum* and *Macrophomina phaseolina* fungi may pose significant future challenges to potato cultivation in this region. *Geotrichum candidum*, is known for causing post-harvest decay, impacting quality and shelf life. Meanwhile, *Macrophomina phaseolina*, a soil-borne pathogen, is the causal agent of charcoal rot in potatoes, affecting both yield and quality. These fungi, if widely established may necessitate a review of disease management strategies, including an effective quarantine system, the development of resistant varieties, effective crop rotation, and fungicide use. Ongoing research and monitoring are crucial for adapting sustainable practices in potato farming, considering the economic implications of these potencial new fungal diseases alongside established diseases.

The field survey showed a high incidence of some field diseases in potato crops including major diseases such as blackleg and late blight, which threaten yield and productivity and ultimately food security. A higher incidence of these diseases was observed in crops produced from locally multiplied seed (LMS) grown in the autumn season, when the environmental conditions are more suitable for disease development due to higher temperatures, rainfall and humidity. In contrast the spring season is characterized as semidry with lower temperatures (Jabbour et al., 2017).

Seed multiplication systems without effective quality control can be very efficient at spreading seed-borne pathogens (Forbes et al., 2020). The Ministry of Agriculture in Syria had started a national project to produce local seed potatoes funded by Japan International Cooperation Agncy (JICA) in 2001, to cover Syrian potato farmers needs for high quality certified seed potatoes (Japan International Cooperation Agncy (JICA), 2001). The ability of growers in the region to produce high quality seeds has been compromised by the current political and economic crisis which led to a lack of scientifically based technical extension work (FAO, 2013). The current situation demands that growers are forced to rely more on informally produced locally multiplied seed with the inherent risks to crop health that follow. Indeed, the conspicuous absence of certified seed potatoes in most low income countries, such as Syria has been documented, and is characterized by the use of less than 10% formal certified seed (Thomas-Sharma et al., 2015). The balance is made up of informally produced seed obtained from own stock, friends, neighbours, relatives, or local markets (McGuire & Sperling, 2016).

It is important to note that this survey did not detect major quarantine pathogens either ISP and LMS. However, the risk of an outbreak of diseases such as these remains while the controls over production are absent and import controls are considerably reduced. Further work to identify the risks and provide local growers with the tools necessary to produce healthy, high yielding potato crops are required.

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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