МИКОЛОГИЯ И ФИТОПАТОЛОГИЯ, 2024, том 58, № 2, с. 161–172

ГРИБЫ – ВОЗБУДИТЕЛИ БОЛЕЗНЕЙ РАСТЕНИЙ

УДК 582.282 : 632.4.01/.08

FUSARIUM SPECIES AFFECTING POTATO TUBERS AND TOMATO FRUITS IN UGANDA

© 2024 A. S. Elansky[1,*], S. M. Mislavskiy[1,], E. M. Chudinova[1,***], L. Yu. Kokaeva[1,2,****], S.N. Elansky[1,2,*****], E. E. Denisova[2,******], I. A. Ilichev[2,*******], A. F. Belosokhov[2,********], Yu. Bamutaze[3,*********], P. Musinguzi[4,**********], E. Opolot[4,**********], and P. V. Krasilnikov[2,***********]**

[1] Peoples Friendship University of Russia named after Patrice Lumumba, 117198 Moscow, Russia
[2] M.V. Lomonosov Moscow State University, 119991 Moscow, Russia
[3] Department of Geography, Geo-Informatics and Climatic Sciences, Makerere University, 7062 Kampala, Uganda
[4] Department of Agricultural Production, School of Agricultural Sciences, Makerere University, 7062 Kampala, Uganda
**e-mail: sasha.elansky@gmail.com*
***e-mail: mislavskiy.sm@yandex.ru*
****e-mail: chudiel@mail.ru*
*****e-mail: kokaeval@gmail.com*
******e-mail: elanskiy_sn@pfur.ru*
*******e-mail: denisova.elizavet@gmail.com*
********e-mail: igor.ilichev.msu@gmail.com*
*********e-mail: arsenybelosokhov.msu.bios@gmail.com*
**********e-mail: yazidhibamutaze@gmail.com*
***********e-mail: patrick.musinguzi@mak.ac.ug*
***********e-mail: oplote@yahoo.com*
************e-mail: pavel.krasilnikov@gmail.com*

Received 18 July, 2023; revised 25 August, 2023; accepted 28 December, 2023

Irish potato and tomato are among the most widely cultivated crops in Uganda. In 2020, samples of affected potato tubers and tomato fruits were collected from farms across four regions in Uganda for analysis. A total of 22 strains of Fusarium spp. were isolated from potato tubers and seven strains were isolated from tomato fruits. Identification of the fungal species was accomplished using cultural and morphological characteristics, as well as DNA sequencing targeting specific regions: ITS1–*5.8S*–ITS2, parts of the elongation factor 1 (*tef 1*) gene, and beta-tubulin (*β-tub*) gene. The analysis of the isolated strains from potato tubers revealed the presence of *Fusarium incarnatum-equisety* species complex, *F. sambucinum* species complex, *F. oxysporum* species complex, *F. solani* species complex. Additionally, *F. incarnatum-equiseti* species complex was detected in tomato fruits. All the investigated strains exhibited the ability to successfully infect both injured tomato fruits and potato tubers. Tested strains were susceptible to difenoconazole (EC50 = 0.08–8.5 mg/L) and thiabendazole (EC50 = 0.67–5.1 mg/L).

Ключевые слова: difenoconazole, dry rot of potato tubers, *Fusarium*, potato diseases, tomato diseases, potato in Uganda, thiabendazole

DOI: 10.31857/S0026364824020077, **EDN:** voxjyk

INTRODUCTION

Irish potato holds great significance as a popular and promising crop in Uganda, playing a pivotal role in the income generation of small farmers. Annually, approximately 327.3 thousand tons of potatoes are cultivated across 111 thousand hectares, yielding an average of seven tons per hectare. It is noteworthy that most potato farming is carried out by small farmers with limited or no formal agricultural training, and their average field size is 1.51 hectares (Potato Roadmap.., 2021). The prevailing choice of potato variety, Victoria, despite its lack of high yield and disease resistance, remains popular due to its early ripening, enabling farmers to harvest twice a year and avoid the challenges of cultivating potatoes during the dry season from November to February.

However, low potato yields pose a significant challenge in the African tropics. An extensive survey (Harahagazwe et al., 2018) conducted among potato growers in sub-Saharan revealed that 95% of farmers attributed low-quality seeds as a leading cause of reduced potato yields. Other factors contributing to this issue included the development of the bacterium *Ralstonia solanacearum*, viral infections,

late blight disease, and poor phytosanitary conditions of soils. The spread of pathogens through seed material or their persistence in the soil was a common observation among farmers. In Uganda, up to 60% of the potato crop is lost annually due to diseases and pests, with pesticide costs accounting for up to 50% of the total product cost.

Tomato cultivation is also prominent in Uganda, offering year-round growth opportunities. Over time, tomato production in the country has seen significant growth, increasing from 5 700 tons in 1972 to 37 654.34 tons in 2021, at an average annual rate of 4.07%.

To effectively protect both potato and tomato crops from diseases, it is necessary to understand the species composition of microorganisms associated with plants. While the populations of late blight pathogens *Phytophthora infestans* (Tumwine et al., 2002; Njoroge et al., 2016, 2019; Namugga et al., 2018) and bacterial wilt *Ralstonia solanacearum* (Abdurahman et al., 2019) have been studied in considerable detail among potato and tomato pathogens in Uganda and works on potato viruses (Byarugaba et al., 2020) and soil biota (Ivanova et al., 2021) have been published, the diversity of fungi infecting these crops remains grossly understudied. Thus, the primary objective of this research is to explore the species diversity of the *Fusarium* genus associated with potato and tomato plants, examining their pathogenicity and resistance to popular fungicides. This study aims to bridge the knowledge gap in this domain and contribute valuable insights for effective disease management strategies in potato and tomato cultivation.

MATERIALS AND METHODS

Samples of infected potato tubers and tomato fruits were collected from farms in different districts of Uganda (Fig. 1). The isolation of fungi was performed by directly transferring affected tissue, mycelium, or spores of the fungus onto Petri dishes containing potato dextrose agar (PDA) supplemented with penicillin (benzylpenicillin sodium salt, 1 million units/L). The selection of spores and mycelium from the samples was carried out with a sterile sharpened preparation needle under a binocular microscope (MBS10, Russia). Strains displaying similar morphology and isolated from the same damaged areas were excluded from consideration to avoid duplication and ensure a representative diversity of fungal species.

To isolate DNA, the mycelium of each fungal culture was ground in a mortar with the addition of aluminum oxide, and the homogenized material was transferred into a 1.5 ml microtube. Subsequently, 800 µl of CTAB lysing buffer [100 mM TRIS Ph 8.0; 1.4 M NaCl, 20 mM EDTA, CTAB solid 2% (W/V)] was added to the tube. The mixture was stirred and then incubated for an hour in a water bath at 65 °C, purified with chloroform treatment, followed by precipitation with a mixture of isopropanol and potassium

Fig. 1. Samples of infected potato tubers and tomato fruits were collected samples were collected in the southwest (1, 2), center (3) and east (4) of Uganda.

acetate (1/10 volume, 5M, pH = 4.6). After washing with 70% ethanol, the DNA was dissolved in deionized water and stored at –20 °C for future use.

PCR was conducted using a Biometra T1 amplifier (Biometra, Germany). For each sample, 0.5 µl of 100 mM forward and reverse primers, 0.5 µl of dNTP (10 mM each), 0.5 µl of DNA polymerase (5 units/µl), 2.5 µl of 10x PCR buffer were taken. DNA fragments ITS1—*5.8S*—ITS2 [(primers ITS4 and ITS5, (White et al., 1990)], β-*tub* gene fragments [Btu-F-F01 and Btu-F-R01, (Watanabe et al., 2011)], and *tef1* were amplified [EF1 and EF2, (O'Donnell et al., 1998)]. The amplification program consisted of an initial denaturation step at 94 °C for 1 minute, followed by 30 cycles of denaturation at 94 °C for 30 seconds, primer annealing (at 52 °C for ITS4/ITS5, 57 °C for Btu-F-F01/Btu-F-R01, and 54 °C for EF1/EF2) for 30 seconds, and elongation at 72 °C for 70 seconds. A final elongation step was performed at 72 °C for 5 minutes. Each PCR experiment included both negative controls (Nucleic acid-free water) and positive controls (known DNA samples expected to yield an amplicon of a specific size). After the PCR reaction, the length and purity of the amplified DNA products were assessed using electrophoresis in a 1% agarose gel containing ethidium bromide. Once the electrophoresis was completed, a gel piece containing the desired amplicon size was excised with a sterile scalpel and placed in a microtube. The extraction of DNA from the gel was performed according to the manufacturer's instructions specified in

the CleanUp Standard gel kit (Evrogen Ltd, Russia). For DNA sequencing, the Sanger method was employed by the Evrogen Ltd company. The obtained DNA sequences were compared with existing sequences from the NCBI GenBank database. DNA sequence analysis was conducted using the MEGA 10 software for further investigation and identification of the isolated *Fusarium* species.

To evaluate the pathogenicity of the strains, small potato tubers (about 40 mm in diam.) and green Cherry tomato fruits were used. After surface sterilization, the tubers and fruits were sliced into slices about 7 mm thick and placed in a humid chamber. Infection was achieved by introducing a block of agar containing mycelium from an axenic culture of the studied strain. As a control, a sterile agar block was placed on a tuber slice. The inoculated tuber slices were placed in humid chambers and kept at 22 °C. Over a period of 7 days the diameters of the damages caused were recorded.

For assessing susceptibility to fungicides, in vitro testing was conducted on nutrient media in Petri dishes. Two fungicides, namely thiabendazole (Tecto, species complex) and difenoconazole (Score, EC), were investigated. The fungicides were added to the PDA medium to obtain a final concentration of the active substance 0.1, 1, 10, 100 mg/L. The fungicide-free medium was used as a control. A block containing mycelium of a studied strain was placed in the center of the Petri dish with the medium. When the diameter of the colony on the control plate was 60—80% of the diameter of the Petri dish, the diameters of the colonies on the media with fungicide were measured, based on which the EC_{50} index (fungicide concentration limiting the radial growth of the colony by two times relative to the control) was calculated.

RESULTS

A total of 22 *Fusarium* spp. strains were isolated from potato tubers and 7 strains from tomato fruits grown in various regions (Table 1).

The analysis of the partial *tef* gene region led to the identification of all studied strains being categorized into four species complexes: *F. incarnatum-equisety* species complex, *F. sambucinum* species complex, *F. oxysporum* species complex, *F. solani* species complex (Table 2, Fig. 2, 3). Among the isolates from potato, representation was observed across all species complexes. Conversely, all isolates from tomato fruits were found to belong solely to *F. incarnatum-equisety* species complex.

Within the *F. sambucinum* species complex one strain isolated from a potato tuber grouped together with strains previously isolated from grain in Belgium, wheat stem in Japan, and another potato tuber in Poland. Additionally, two genetically similar isolates were grouped with *F. solani* species complex strains. One of these strains originated from Spanish soil, while the other was isolated from an Algerian potato tuber.

The largest number of analyzed strains belonged to the *F. incarnatum-equiseti* species complex and *F. oxysporum* species complex. Specifically, *F. oxysporum* species complex comprised 15 strains isolated from potato tubers, displaying minimal differences among them. Strains previously isolated from potato tubers in Russia and Poland also were found within this species complex.

The *F. incarnatum-equiseti* species complex demonstrated notably higher diversity. It included three strains isolated from potato tubers and six strains from tomato fruits. Potato strains have been isolated from tubers grown in different regions of Uganda. Genetically, these strains were identical in the *tef* gene region and grouped together with a strain isolated from soil in the Netherlands, identified by the authors as *F. flageliforme*. In contrast, the tomato strains within the *F. incarnatum-equisety* species complex showed greater diversity and were divided into four distinct groups, with three of these groups represented by a single strain each. Noteworthy associations were observed, such as strain 20UgTF2 grouping with a strain previously isolated from eggplant in Tanzania, 20UgTF3 grouping with peanut strains from Mexico and Brazilian wheat, and 20UgLaTF9 grouping with a banana strain from Tanzania. Moreover, genetically similar strains, namely 20UgLaTF7, 20UgLaTF1, 20UgTF5/1, and 20UgLaTF5/2, isolated from tomato fruits in distant parts of Uganda, were closely related to the strain from the *F. incarnatum-equiseti* species complex, identified as *F. citri*.

The concatenated sequences of two genes *tef* and *tub* were analyzed in a subset of 16 strains, with four isolated from tomato fruits and the remainder from potato tubers (Fig. 3). The analysis largely revealed patterns consistent with the *tef* gene sequence analysis. However, it is worth noting that only a few strains with the analyzed *tub* sequences have been deposited in the databases, posing challenges in the identification of strains using concatenated *tef* and *tub* gene sequences.

Pathogenicity testing revealed differences between strains within all studied species and species complexes (Table 3). All fungal species analyzed developed much better growth on a tomato slices compared to potato slices.

An experiment was carried out to evaluate the susceptibility of the tested strains to fungicides (Table 4). Under laboratory conditions, on a nutrient medium with varying concentrations of fungicides, the vast majority of tested *Fusarium* spp. were highly susceptible to difenoconazole (EC_{50} < 1 mg/L). Increased resistance (EC_{50} = 8.5 mg/L) to this fungicide was found in a single strain (20UgLaPT2_1) from the *F. graminearum* species complex

Table 1. Reference strains used in the present study

Species	Strain identifier	Origin (country, substrate)	GenBank NCBI accession number		
			ITS	*tub*	*tef*
Fusarium incarnatum-equiseti species complex (= *F. flagelliforme*)	26MPL17AB	Russia, PL		ON292470	ON292364
F. incarnatum-equiseti species complex (= *F. citri*)	NRRL 25084	Austria, *Adelphocoris* sp.			JF740715
F. incarnatum-equiseti species complex (= *F. equiseti*)	Z331	Poland, PT	KP264661	KP674236	KP400714
" "	31MPL17AB	Russia, PL		ON292431	ON292366
F. incarnatum-equiseti species complex (= *F. flagelliforme*)	NL19—052002	Netherlands, soil	MZ890499		MZ921842
F. incarnatum-equisety species complex (= *F. semitectum*)	CAV2580	Tanzania, banana			KX365415
F. incarnatum-equiseti species complex	R2PS(A)	Algeria, PT	MK752405	MK752398	MK752460
" "	FS5	Tanzania, egg-plant	JQ244854		JQ244848
" "	MA-PET-03	Mexico, peanut root			OQ679821
" "	F1009	Brasil, wheat			MN958256
F. oxysporum species complex (f. sp. *batatas*)	l73VPT19AB	Vietnam, PT		ON292476	ON292417
F. oxysporum species complex	MFG 70165	Russia, PT			OR020727
" "	NRRL 52785				JF740853
" "	Z322C	Poland, PT	KP264657	KP674232	KP400710
F. sambucinum species complex (= *F. asiaticum*)	RTT17	Japan, wheat stem	LC500061		LC500694
F. sambucinum (= *F. boothii*)	MBC7644	Belgium, grain			KX881786
F. sambucinum species complex (= *F. graminearum*)	M216A	Poland, PT	KP295509	KP765707	KP400687
F. solani species complex (= *F. bostrycoides*)	NRRL 52701		JF740906		JF740784
F. solani species complex (= *F. tonkinense*)	7B	Algeria, PT			MK752499
F. solani species complex	ML	Spain, soil			MH300508
" "	147MPT17AB	Russia, PT		ON292467	ON292380

Note. PT — potato tuber; PL — potato leaf.

Table 2. Description of strains isolated

Species	Strain	Collection site (Fig. 1)	Host plant	ITS	*tef*	*tub*
Fusarium incarnatum-equiseti species complex	20UgTF_2	3	T	OM421612	OM362484	
" "	20UgTF3	3	T	OM421613	OM362475	OM362470
" "	20UgTF5/1	3	T	OM421614	OM362476	OM362471
" "	20UgTF5/2	3	T	OM421615	OM362478	OM362472
" "	20UgLaTF1	2	T	OM421616	OM362479	
" "	20UgLaTF7	2	T	OM421617	OM362477	OM362469

Table 2. Continuation

" "	20UgLaTF9/1	2	T		OM362480	
F. sambucinum species complex	20UgLaPT2/1	2	P	OL364745	OM830309	OM830308
F. incarnatum-equiseti species complex	20UgLaPT1	2	P		OM362481	OM362473
" "	20UgPT208	3	P	OM421619	OM362482	
" "	20UgPT211	3	P	OM421620	OM362483	
F. oxysporum species complex	20UgMbPT5/2	4	P	OL372289	OM649880	OM649892
" "	20UgKgPT1/3	1	P		OM649878	
" "	20UgKgPT3	1	P	OL372288	OM649879	OM649896
" "	20UgPT4/1	3	P	OL372290	OM649877	OM649893
" "	20UgPT5	3	P		OM649875	OM649894
" "	20UgKacPT15	1	P	OL372285	OM649886	OM649895
" "	20UgPT195	3	P	OL372293	OM649881	OM649889
" "	20UgPT199	3	P	OL372291	OM649876	
" "	20UgPT200	3	P		OM649882	
" "	20UgPT201	3	P		OM649885	OM649888
" "	20UgPT205	3	P		OM649887	OM649891
" "	20UgPT206	3	P		OM649873	
" "	20UgPT217	3	P	OL372287	OM649883	
" "	20UgPT241	3	P	OL372292	OM649884	
" "	20UgPT242	3	P		OM649874	
F. solani species complex	20UgPT204	3	P		OM743507	OM801560
" "	20UgPT197	3	P		OM743506	
" "	20UgMbPT3/1	4	P	OM662233	OM743505	OM801559

Note. T — tomato; P — potato.

complex. All tested strains were susceptible to thiabendazole too (EC_{50} < 5.1 mg/L).

DISCUSSION

The examination of cultural and morphological characteristics, along with the analysis of species-specific regions in the studied strains, made it possible to identify fungal species present on potato tubers and tomato fruits in Uganda. being a highly diverse group of fungi, exhibits variations in its physiological characteristics. As new data on the phylogeny of the genus are obtained, its species composition changes (O'Donnell et al., 2015, 2022).

Based on our findings, *Fusarium* strains isolated from potato tubers in Uganda can be classified into four species complexes: *F. incarnatum-equisety* species complex, *F. sambucinum* species complex, *F. oxysporum* species complex, *F. solani* species complex (Table 2, Fig. 2, 3). Most potato strains are represented by *F. oxysporum* species complex, that also dominated in potato tubers in Poland (Stefańczyk et al., 2016) Michigan state USA (Gachango et al., 2012) and South Korea (Kim, Lee, 1994) (Table 5). Strains of *F. oxysporum* species complex were also found in potato tubers in Vietnam (unpublished data from our laboratory). In Algeria and China *F. sambucinum* prevails instead (Azil et al., 2021; Du et al., 2012). *F. solani* species complex dominated in England from 2000—2002 (Peters et al., 2008). Nevertheless, it is essential to acknowledge that the species identified in previous works may not align with the current taxonomy, considering the revision of the phylogeny of the genus.

F. incarnatum-equiseti species complex were noted in all countries, while *F. solani* species complex strains were found everywhere except China. *F. sambucinum* species complex was identified in all countries, *F. tricinctum* species complex was absent in Uganda. Species of the *F. fujikuroi* species complex were present in Algeria. These findings imply that the sample size might not be sufficient to fully ascertain the species and species complexes of *Fusarium* spp. in Uganda.

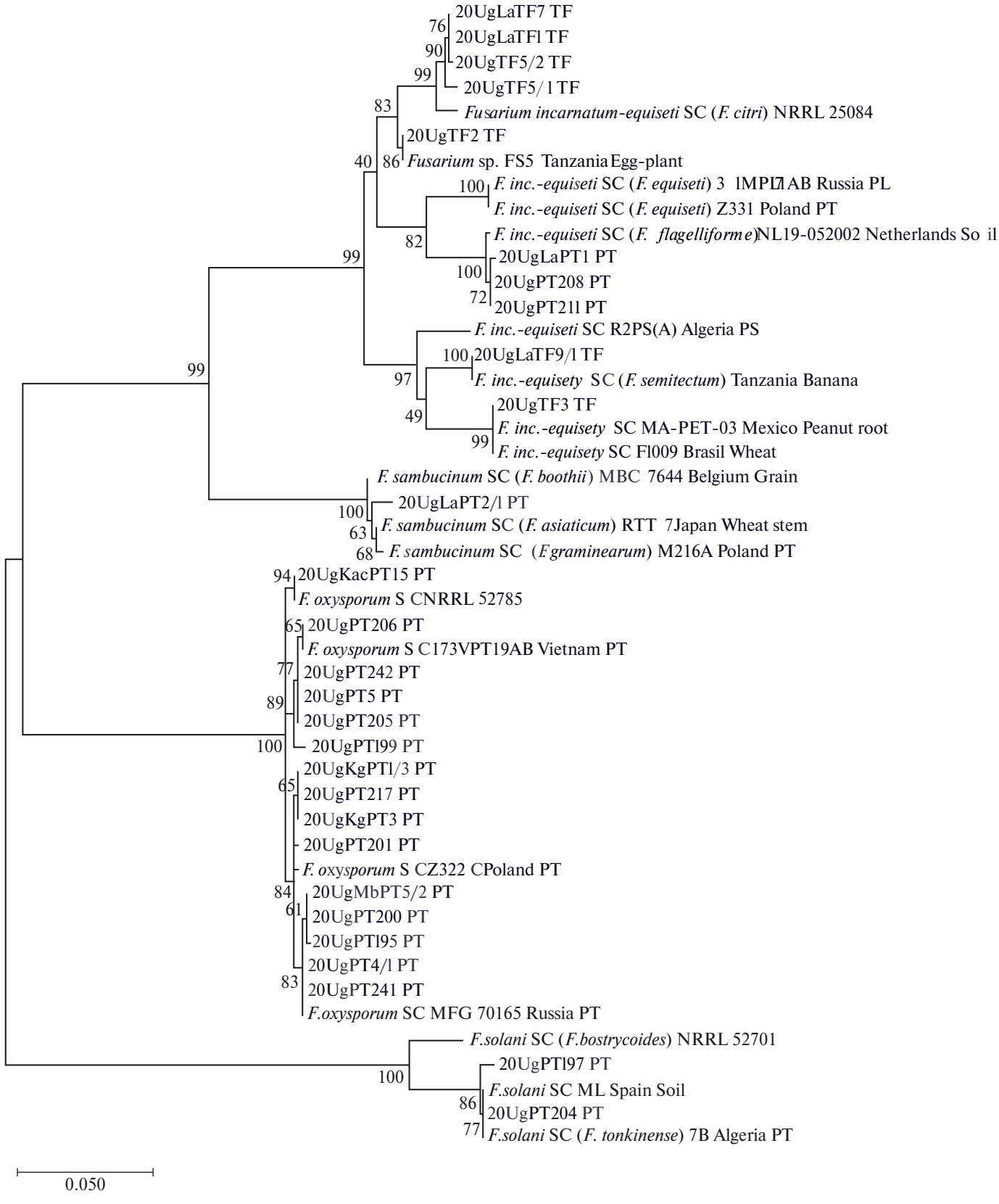

Fig. 2. Phylogenetic tree inferred from maximum-likelihood analysis of the concatenated alignment, including partial *tef* gene region (675 bp). The confidence values are indicated at the branches (1000 bootstrap replicates). PT, PL, PS — isolates from potato tubers, leaves, stems correspondingly, TF — from tomato fruits, SC — species complex.

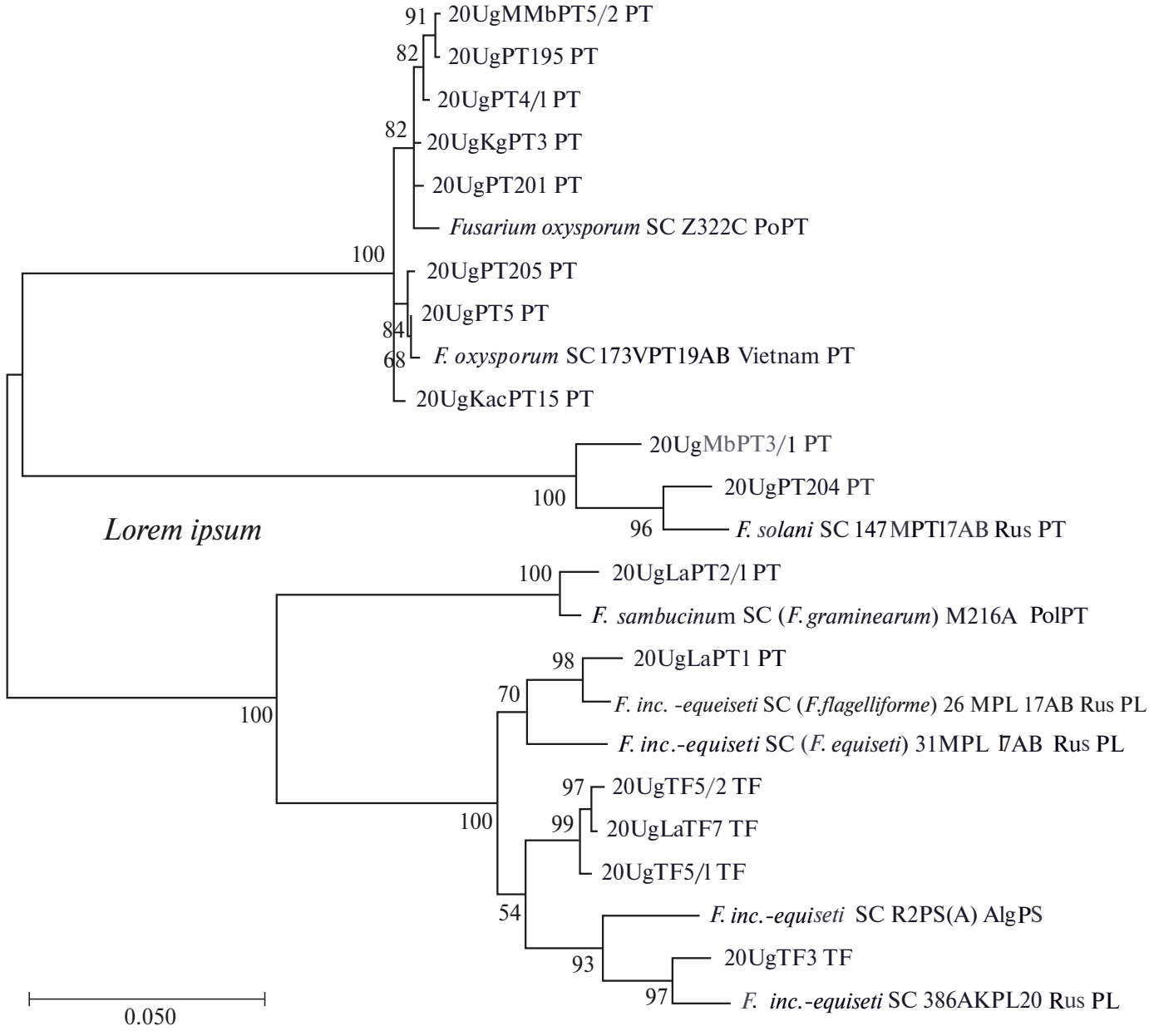

Fig. 3. Phylogenetic tree inferred from maximum-likelihood analysis of the concatenated alignment, including partial *tef* and *tub* gene regions (1230 bp). The confidence values are indicated at the branches (500 bootstrap replicates). PT, PL, PS — isolates from potato tubers, leaves, stems correspondingly, TF — from tomato fruits.

Separate strains of *Fusarium* and related species from the CBS collection were tested and identified at the species level in studies dedicated to the phylogeny of the genus. For instance, the work of Crous et al. (2021), an analysis of specific DNA regions of *F. sambucinum* (*F. sambucinum* species complex), *F. martii*, *F. noneumartii*, *F. paraeumartii*, and *F. solani* (all *F. solani* species complex) strains isolated from potato and *F. tonkinense* (*F. solani* species complex) from tomato is presented. This adds to the understanding of the genetic diversity within the *Fusarium* genus and aids in refining the classification of species in this group.

In tomato, we found strains belonging to the *F. incarnatum-equiseti* species complex. A study of *Fusarium* lesions of tomatoes in Northern Pakistan, reported 68.9% of infections being caused by *F. incarnatum-equiseti* species complex, followed by 20.7% *F. graminearum* species complex, 6.8% *F. acuminatum*, and 6.8% *F. solani* (Akbar et al., 2018). Additionally, representatives of the *F. oxysporum* species complex were found on tomato plants in various countries including Nigeria (Srinivas et al., 2019; Borisade et al., 2017). In Uganda we found one strain of *F. oxysporum* species complex in tomato fruit, but its *tef1*α

Table 3. Pathogenicity testing of *Fusarium* representatives isolated from various Uganda localities on potato and tomato slices

Species	Strain	Host plant	Lesion diameter on potato slices, mm	Lesion diameter on tomato slices, mm
Fusarium incarnatum-equiseti species complex	20UgTF_1	T	12*	12
F. incarnatum-equiseti species complex	20UgTF_2	T	7.5	15
“ “	20UgTF3	T	23.25	28.025
“ “	20UgTF5_1	T	9.3	13
“ “	20UgLaTF1	T	14.7	28
“ “	20UgLaTF7	T	14.4	28
“ “	20UgLaTF9_1	T	5.7	22.48
“ “	20UgPT208	P	4.8	7.5
“ “	20UgLaPT1	P	7.6	25
F. sambucinum species complex	20UgLaPT2_1	P	35.3	32
F. oxysporum species complex	20UgMbPT5_2	P	10.7	15.5
“ “	20UgKgPT1_3	P	8	19.5
“ “	20UgKgPT3	P	10.7	29
“ “	20UgKacPT_15	P	12.7	22
“ “	20UgPT4_1	P	6	19
“ “	20UgPT5	T	11.3	26.5
“ “	20UgPT195	P	13	16
“ “	20UgPT200	P	23	20
“ “	20UgPT201	P	11	14
“ “	20UgPT205	P	15.7	20
“ “	20UgPT206	P	18.3	22
“ “	20UgPT217	P	6.5	20.5
“ “	20UgPT241	P	9.33	21
“ “	20UgPT242	P	13.7	10
“ “	20UgPT243	P	9.33	23
F. solani species complex	20UgMbPT3_1	P	15.1	20.65
“ “	20UgPT197	P	6.67	14

Note. T — tomato; P — potato; *average diameters of three replications.

Table 4. Sensitivity of tested fungal strains to fungicides difenoconazole and thiabendazole

Species	Strain	Host plant	Sensitivity to fungicides, EC_{50}, mg/L	
			difenoconazole	thiabendazole
Fusarium incarnatum-equiseti species complex	20UgTF_1	T	0.09	0.54
“ “	20UgTF_2	T	0.08	not tested
“ “	20UgTF5_1	T	0.1	not tested
“ “	20UgLaTF1	T	0.92	0.77
“ “	20UgLaTF7	T	0.1	not tested
F. oxysporum species complex	20UgLaTF4	T	0.51	0.85
F. sambucinum species complex	20UgLaPT2_1	P	8.5	2.78

F. incarnatum-equiseti species complex	20UgPT208	P	0.08	0.73
F. oxysporum species complex	20UgPT4_1	P	0.48	3
" "	20UgPT5	P	0.38	3.7
" "	20UgKgPT1_3	P	0.42	2.63
" "	20UgKgPT3	P	0.88	3.8
" "	20UgKacPT_15	P	0.13	0.98
" "	20UgPT200	P	0.87	4.17
" "	20UgPT206	P	0.79	4.32
" "	20UgPT242	P	0.3	5.1
F. solani species complex	20UgPT197	P	7.3	4.82

Note. T — tomato; P — potato.

Table 5. *Fusarium* species complexes on potato tubers in different countries (% of infections)

Species or species complexes	Uganda	Poland	Algeria	US	China
Fusarium merismoides		0.7			
F. torulosum				2.2	
F. redolens species complex		3.5	1.1		
F. incarnatum-equiseti species complex	13.8	0.7	8.6	19.2	3.1
F. oxysporum species complex	58.6	47.2		30.3	9.2
*F. sambucinu*m species complex	6.9	23.4	82.7	22	56.2
*F. solan*i species complex	20.7	11.3	5.4	7.5	
F. tricinctum species complex		12.7	1.1	19.8	30
F. fujikuroi species complex			1.1		
Total number of analyzed samples	29	142	93	228	260
DNA regions, used for analysis	β-*tub*, *tef1*α	β-*tub*, *tef1*α	*tef1*α	*tef1*α	*tef1*α

region was not sequenced. Its species was determined by the DNA sites β-*tub* (OM649897) and ITS (OL372284).

In our experiments, all tested *Fusarium* spp. strains successfully infected slices of both potato tubers and tomato fruits. Similar results were observed in studies with strains isolated from Poland, Algeria (Stefańczyk et al., 2016; Azil et al., 2021), and Vietnam (unpublished data). A particularly aggressive *F. incarnatum-equiseti* species complex strain isolated from tomato in South-Western Russia was able to infect the tomato fruits directly through the intact epidermis (Chudinova et al., 2020).

Regarding resistance to fungicides, our study revealed that all tested strains were susceptible to difenoconazole (EC_{50} = 0.08—8.5 mg/L) and thiabendazole (EC_{50} = 0.67—5.1 mg/L). These concentrations are significantly lower than the concentration of thiabendazole in the working fluid for treating tubers (for example, in the working liquid for tuber treatment before planting concentration of thiabendazole 4800 mg/L). As a result, all the strains studied can be considered susceptible to these fungicides.

In the literature, we could not find any data on *Fusarium* strains resistant to difenoconazole. However, there is evidence of increased resistance to difenoconazole (EC_{50} = 19.2 mg/L, Rekanović et al., 2010) and the ability of *Fusarium* strains to adapt to triazoles by overexpressing drug resistance transporters (Hellin et al., 2018).

Fusarium spp. strains with increased levels of resistance to thiabendazole were found among potato tubers isolated in the USA in 1992—1993 (Hanson et al., 1996). There EC_{50} values were more than 30 mg/L. Strains with increased resistance were found in Germany (Langerfeld, 1990) and Canada (Peters et al., 2001). An analysis of strains of *F. sambucinum* isolated in different years from samples collected in North America (Desjardins et al.,

1993) showed changes in resistance to thiabendazole at the turn of 1986—1991 years. Thus, 17 strains isolated between 1963 and 1986 were susceptible to thiabendazole (EC_{50} < 2 mg/L), while strains isolated in 1990—1991 had significantly higher resistance (EC_{50} = 26—48 mg/L). However, it's important to note that among the studied *Fusarium* strains (including those in our study and the literature), no high levels of resistance (EC_{50} > 100 mg/L) were observed.

CONCLUSION

In conclusion, it is evident that the species diversity of fungi that infect potato tubers and tomato fruits in the tropical zone remains poorly studied and is often overlooked when developing protective measures. It is crucial to recognize that different *Fusarium* species exhibit variations in pathogenicity and susceptibility to fungicides (Hanson et al., 1996). Consequently, further research on the mycobiota of potato and tomato is highly relevant and should be pursued. Understan- ding the composition of fungal species that affect these crops can lead to the development of more effective and targeted strategies for disease management, thus enhancing agricultural productivity and food security in the tropical regions. Continued efforts in this area will undoubtedly contribute to the advancement of agricultural practices and sustainable crop protection.

This research was supported by the Russian Science Foundation (grant N 23-16-00048).

REFERENCES

Abdurahman A., Parker M.L., Kreuze J. et al. Molecular epidemiology of *Ralstonia solanacearum* species complex strains causing bacterial wilt of potato in Uganda. Phytopathology. 2019. V. 109. P. 1922—1931. https://doi.org/10.1094/PHYTO-12-18-0476-R

Akbar A., Hussain S., Ullah K. et al. Detection, virulence, and genetic diversity of *Fusarium* species infecting tomato in Northern Pakistan. PLOS One. 2018. V. 13 (9). P. e0203613. https://doi.org/10.1371/journal.pone.0203613

Azil N., Stefańczyk E., Sobkowiak S. et al. Identification and pathogenicity of *Fusarium* spp. associated with tuber dry rot and wilt of potato in Algeria. Eur. J. Plant Pathol. 2021. V. 159. P. 495—509. https://doi.org/10.1007/s10658-020-02177-5

Borisade O.A., Uwaidem Y.I., Salami A.E. Preliminary report on *Fusarium oxysporum* f. sp. *Lycopersici* (sensu lato) from some tomato producing agroecological areas in Southwestern Nigeria and susceptibility of F1-resistant tomato hybrid (F1-Lindo) to infection. Ann. Res. Rev. Biol. 2017. V. 18 (2). P. 1—9. https://doi.org/10.9734/ARRB/2017/34626

Byarugaba A.A., Mukasa S.B., Barekye A. et al. Interactive effects of Potato virus Y and Potato leafroll virus infection on potato yields in Uganda. Open Agriculture. 2020. V. 5. P. 726—739. https://doi.org/10.1515/opag-2020—0073

Chudinova E.M., Shkunkova T.A., Elansky S.N. Fungal pathogens of tomato in South-Western Russia (Krasnodar territory). Plant Protection News. 2020. V. 103 (3). P. 210—212. http://dx.doi.org/10.31993/2308-6459-2020-103-3-4998

Crous P.W., Lombard L., Sandoval-Denis M. et al. Fusarium: More than a node or a foot-shaped basal cell. Stud. Mycol. 2021. V. 98. P. 100116. https://doi.org/10.1016/j.simyco.2021.100116

Desjardins A.E., Christ-Harned E.A., McCormick S.P. et al. Population structure and genetic analysis of field resistance to thiabendazole in *Gibberella pulicaris* from potato tubers. Phytopathology. 1993. V. 83 (2). P. 164—170.

Du M., Ren X., Sun Q. et al. Characterization of *Fusarium* spp. causing potato dry rot in China and susceptibility evaluation of Chinese potato germplasm to the pathogen. Potato Res. 2012. V. 55. P. 175—184. http://dx.doi.org/10.1007/s11540-012-9217-6

Gachango E.; Hanson L.E.; Rojas A. et al. Fusarium spp. causing dry rot of seed potato tubers in Michigan and their sensitivity to fungicides. Plant Disease. 2012. V. 96. P. 1767—1774. https://doi.org/10.1094/pdis-11-11-0932-re

Hanson L.E., Schwager S.J., Loria R. Sensitivity to thiabendazole in *Fusarium* species associated with dry rot of potato. Phytopathology. 1996. V. 86. P. 378—384.

Harahagazwe, D., Condori B., Barreda C. et al. How big is the potato (*Solanum tuberosum* L.) yield gap in Sub-Saharan Africa and why? A participatory approach. Open Agriculture. 2018. V. 3. P. 180—189. https://doi.org/10.1515/opag-2018-0019

Hellin P., King R., Urban M. et al. The adaptation of *Fusarium culmorum* to DMI fungicides is mediated by major transcriptome modifications in response to azole fungicide, including the overexpression of a PDR transporter (FcABC1). Front. Microbiol. 2018. V. 9. Art. 1385. https://doi.org/10.3389/fmicb.2018.01385

Ivanova A.E., Denisova E., Musinguzi P. et al. Biological indicators of soil condition on the Kabanyolo experimental field, Uganda. Agriculture. 2021. V. 11. P. 1228. http://dx.doi.org/10.3390/agriculture11121228

Kim J.C., Lee Y.W. Sambutoxin, a new mycotoxin produced by toxic *Fusarium* isolates obtained from rotted potato tubers. Appl. and Env. Microbiol. 1994. V. 60. P. 4380—4386.

Langerfeld E. Resistance to thiabendazol of *Fusarium coeruleum*. Nachrichtenblatt des Deutschen Pflanzenschutzdienstes. 1990. V. 42 (5). P. 79.

Namugga P., Sibiya J., Melis R. et al. Yield response of Potato (*Solanum tuberosum* L.) genotypes to late blight caused by *Phytophthora infestans* in Uganda. Am.J. Pot. Res. 2018. V. 95. P. 423—434. https://doi.org/10.1007/s12230-018-9642-4

Njoroge A.W., Andersson B., Yuen J.E. et al. Greater aggressiveness in the 2_A1 lineage of *Phytophthora infestans* may

partially explain its rapid displacement of the US-1 lineage in east Africa. Plant Pathol. 2019. V. 68. P. 566—575. https://doi.org/10.1111/ppa.12977

Njoroge A.W., Tusiime G., Forbes G.A., et al. Displacement of US-1 clonal lineage by a new lineage of *Phytophthora infestans* on potato in Kenya and Uganda. Plant Pathol. 2016. V. 65. P. 587—592.https://doi.org/10.1111/ppa.12451

O'Donnell K., Kistler H.C., Cigelnik E. et al. Multiple evolutionary origins of the fungus causing Panama disease of banana: Concordant evidence from nuclear and mitochondrial gene genealogies. Proc. Natl. Acad. Sci. USA. 1998. V. 95. P. 2044—2049.

O'Donnell K., Ward T.J., Robert V.A.R.G. et al. DNA sequence-based identification of *Fusarium*: current status and future directions. Phytoparasitica. 2015. V. 43. P. 583—595. https://doi.org/10.1007/s12600-015-0484-z

O'Donnell K., Whitaker B.K., Laraba I. et al. DNA Sequence-Based Identification of *Fusarium*: A Work in Progress. Plant Dis. 2022. V. 106 (6). P. 1597—1609. https://doi.org/10.1094/PDIS-09-21-2035-SR

Peters J.C., Lees A.K., Cullen D.W. et al. Characterization of *Fusarium* spp. responsible for causing dry rot of potato in Great Britain. Plant Pathol. 2008. V. 57. 262—271. https://doi.org/10.1111/j.1365-3059.2007.01777.x

Peters R.D., Macdonald I.K., MacIsaac K.A. et al. First report of thiabendazole-resistant isolates of *Fusarium sambucinum* infecting stored potato in Nova Scotia, Canada. Plant Disease. 2001. V. 85 (9). 1030. https://doi.org/10.1094/PDIS.2001.85.9.1030A

Potato Roadmap Uganda 2021. Ministry of foreign affairs. Haag, 2021.

Rekanović E., Mihajlović M., Potočnik I. In vitro sensitivity of *Fusarium graminearum* (Schwabe) to difenoconazole, prothioconazole and thiophanate-methyl. Pestic. Phytomed. (Belgrade). 2010. V. 25 (4). P. 325—333. http://dx.doi.org/10.2298/PIF1004325R

Srinivas C., Nirmala Devi D., Narasimha Murthy K. et al. Fusarium oxysporum f. sp. *lycopersici* causal agent of vascular wilt disease of tomato: Biology to diversity. A review. Saudi J. Biol. Sci. 2019. V. 26 (7). P. 1315—1324. https://doi.org/10.1016/j.sjbs.2019.06.002

Stefańczyk E., Sobkowiak S., Brylińska M. et al. Diversity of *Fusarium* spp. associated with dry rot of potato tubers in Poland. Eur. J. Plant Pathol. 2016. V. 145. P. 871—884. https://doi.org/10.1007/s10658-016-0875-0

Tumwine J., Frinking H.D., Jeger M.J. Tomato late blight (*Phytophthora infestans*) in Uganda. Int. J. of Pest Management. 2002. V. 48 (1). P. 59—64. https://doi.org/10.1080/09670870110094350

Watanabe M., Yonezawa T., Lee K. et al. Molecular phylogeny of the higher and lower taxonomy of the Fusarium genus and differences in the evolutionary histories of multiple genes. BMC evolutionary biology. 2011. V. 11. P. 322. https://doi.org/10.1186/1471-2148-11-322

White T.J., Bruns T., Lee S.J.W.T. et al. Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In: *M.A. Innis, D.H. Gelfand, J.J. Sninsky, T.J. White* (eds). PCR-protocols and applications — a laboratory manual. Academic Press, San Diego, 1990, pp. 315—322.

Виды рода *Fusarium*, поражающие клубни картофеля и плоды томата в Уганде

А.С. Еланский[a,#], С.М. Мирославский[b,##], Е.М. Чудинова[a,###], Л.Ю. Кокаева[a, b,####], С.Н. Еланский[a, b,#####], Е.Е. Денисова[b,######], И.А. Ильичев[b,#######], А.Ф. Белосохов[b,########], Я. Бамутазе[c,#########], П. Музингузи[d,##########], Е. Ополот[d,###########], П.В. Красильников[b,############]

[a] Российский университет дружбы народов имени Патриса Лумумбы, Москва, Россия
[b] Московский государственный университет имени М.В. Ломоносова, Москва, Россия
[c] Университет Макерере, факультет географии, геоинформатики и климата, Кампала, Уганда
[d] Университет Макерере, кафедра сельскохозяйственной продукции, факультет сельскохозяйственных наук, Кампала, Уганда
**e-mail: sasha.elansky@gmail.com*
***e-mail: mislavskiy.sm@yandex.ru*
****e-mail: chudiel@mail.ru*
*****e-mail: kokaeval@gmail.com*
******e-mail: elanskiy_sn@pfur.ru*
*******e-mail: denisova.elizavet@gmail.com*
********e-mail: igor.ilichev.msu@gmail.com*
*********e-mail: arsenybelosokhov.msu.bios@gmail.com*
**********e-mail: yazidhibamutaze@gmail.com*
***********e-mail: patrick.musinguzi@mak.ac.ug*
************e-mail: oplote@yahoo.com*
*************e-mail: pavel.krasilnikov@gmail.com*

Картофель и томат являются одними из наиболее широко возделываемых культур в Уганде. В 2020 г. 22 штамма *Fusarium spp.* были выделены из клубней картофеля и семь штаммов из плодов томата. Образцы были собраны на фермах в четырех регионах Уганды. Идентификацию видов грибов проводили с использованием культурально-морфологических характеристик и секвенирования части генов фактора элонгации 1 (*tef 1*) и бета-тубулина (*β-tub*), а также региона ITS1—*5.8S*–ITS2 (ITS). Анализ выделенных штаммов из клубней картофеля выявил наличие видовых комплексов *Fusarium oxysporum* species complex, *F. solani* species complex, *F. sambucinum* species complex, *F. incarnatum-equiseti* species complex. В плодах томата был обнаружен только F. *incarnatum-equiseti* species complex. Все проанализированные штаммы проявляли способность успешно заражать как поврежденные плоды томата, так и клубни картофеля. Анализ устойчивости к фунгицидам показал, что исследуемые штаммы были чувствительны к дифеноконазолу (EC_{50} = 0.08—8.5 мг/л) и тиабендазолу (EC_{50} = 0.67—5.1 мг/л).

Ключевые слова: фузариоз картофеля, фузариоз томата, сухая гниль клубней картофеля, тропическое овощеводство