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EVALUATION OF TOMATO GENOTYPES FOR TOLERANCE TO MAJOR DISEASES IN UGANDA

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is a priority vegetable in Uganda, but due to its limited genetic base, its cultivated types are prone to a variety of diseases. The objective of this study was to evaluate new tomato genotypes for resistance to major tomato diseases under hotspot conditions in Uganda. Fourty-five tomato genotypes were evaluated for reactions to tomato bacterial wilt, tomato bacterial speck, early blight and late blight. The study was conducted for two rainy seasons in 2019, at the National Crops Resources Research Institute, Namulonge in Uganda. Data for severity and incidence were collected at two-week intervals after transplanting. Twelve genotypes (Nouvella F_1, Rambo F_1, Commando F_1, AVTO1315, AVTO922, AVTO1701, AVTO1219, AVTO1464, MT56, ADV1287A, Pruna and Vega) exhibited high levels of tolerance to bacterial wilt; while bacterial speck presented mild symptoms majorly seen on Vega, Zodiac and AVTO9802. Rhino, AVTO1418, AVTO1314, Eureka, Roma VFN, MT56, Pinktop, Assila F_1, Money-maker, AVTO0922 and AVTO1464 were the least affected by early blight; while AVTO1219, AVTO1701, ADV12021, ADV12076 and ADV1287A expressed low AUDPC values for late blight. Overall, AVTO1315 was the best yielder (30.8 metric tonnes ha^{-1}), followed by AVTO0301 (29.0 t ha^{-1}) and Nouvella F_1 (26.1 t ha^{-1}). Among the tomato genotypes evaluated, we recommend AVTO1701, AVTO0922, AVTO1464, AVTO0301 AVTO1315, AVTO1219, Pruna, Vega, ADV1287A and MT56 for the national performance trials.

Key Words: Bacteria, blight, severity, *Solanum lycopersicum*

RÉSUMÉ

La tomate (*Solanum lycopersicum* L.) est un légume prioritaire en Ouganda, mais en raison de sa base génétique limitée, ses types cultivés sont sujets à une variété de maladies. L'objectif de cette étude était d'évaluer des génotypes de tomates sélectionnés pour leur résistance aux principales maladies de la tomate dans des conditions de hotspot en Ouganda. Quarante-cinq génotypes de tomates ont été évalués pour leurs réactions au flétrissement bactérien de la tomate, à la tache bactérienne de la tomate, au mildiou et au mildiou. L'étude a été menée pendant deux saisons des pluies en 2019, au National Crops Resources Research Institute, à Namulonge en Ouganda. Les données de gravité et

d'incidence ont été recueillies à des intervalles de deux semaines après la transplantation. Douze génotypes (Nouvella F1, Rambo F1, Commando F1, AVTO1315, AVTO922, AVTO1701, AVTO1219, AVTO1464, MT56, ADV1287A, Pruna et Vega) présentaient des niveaux élevés de tolérance au flétrissement bactérien; tandis que la tache bactérienne présentait des symptômes bénins principalement observés sur Vega, Zodiac et AVTO9802. Rhino, AVTO1418, AVTO1314, Eureka, Roma VFN, MT56, Pinktop, Assila F1, Money-maker, AVTO0922 et AVTO1464 ont été les moins touchés par le mildiou; tandis que AVTO1219, AVTO1701, ADV12021, ADV12076 et ADV1287A ont exprimé de faibles valeurs AUDPC pour le mildiou. Dans l'ensemble, AVTO1315 a été le meilleur producteur (30,8 tonnes métriques ha^{-1}), suivi par AVTO0301 (29,0 t ha^{-1}) et Nouvella F1 (26,1 t ha^{-1}). Parmi les génotypes de tomates évalués, nous recommandons AVTO1701, AVTO0922, AVTO1464, AVTO0301 AVTO1315, AVTO1219, Pruna, Vega, ADV1287A et MT56 pour les essais de performance nationaux.

Mots Clés: Bactéries, brûlure, gravité, *Solanum lycopersicum*

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is the second most important vegetable crop globally, next to potato (*Solanum tuberosum*), with an estimated global annual production of 188 million metric tonnes, from 4.8 million hectares (FAO, 2018). In East Africa, tomato constitutes a major home garden commodity for consumption, as well as for sale; with commercial production on the rise (USAID, 2015). In Uganda, tomatoes are majorly produced by subsistence farmers, using genotypes that overly succumb to various diseases.

Diseases, namely Bacterial wilt (*Ralstonia solanacearum*), Bacterial speck (*Pseudomonas syringae* pv *tomato*), Early blight (*Alternaria solani*), and Late blight (*Phytophthora infestans*) are the main constraints to tomato production in Uganda (Mwaule, 1995; Ssekyewa, 2006). Infections caused by these pathogens reportedly cause yield losses of up to 100% *(*Asiimwe *et al.,* 2013; Meitei *et al*., 2014), thus jeopardising the livelihood of millions of growers and other beneficiaries along the crop value chain.

Management of tomato diseases in Uganda is majorly by crop rotation, mulching, plant spacing and fungicide applications. Currently, these practices have been rated ineffective due to improper application, adulterated pesticides and lack of tolerant cultivars (Asiimwe *et al*., 2013; Meitei *et al*., 2014; Meya *et al*., 2014). Tomato farmers in Uganda are small and medium scaled and, therefore, would require affordable high yielding, and market preferred varieties, but at the same time tolerant or resistant to the majority of common tomato diseases in the field. It is well known that the successful production of tomatoes depends on the choice of varieties for a particular location (Chaerani, 2006).

Based on this background, this study was conducted to evaluate new tomato genotypes from Korea, Malawi and Tanzania for their reaction to major tomato diseases in Uganda.

MATERIALS AND METHODS

Study site. This study was conducted on-station at the National Crops Resources Research Institute (NaCRRI), Namulonge in Central Uganda, at latitude 0° 322 N, longitude 32°372 E, and at altitude 1150-1155 m above sea level. The annual mean day temperatures range from 24 to 30 °C. The rainfall is bimodal, with a mean annual amount of 1000 to 1450 mm.

The soil types are acidic, with a pH ranging from 6.5 to 7.0. The vegetation is characterised as tropical wet and with Ferralsols mild dry climate with slight humid conditions (65% relative humidity), which are suitable for tomato growing (Nsubuga *et al*., 2011).

Pathogen inoculation. The specific site used for this study had a history of being heavily infested with *Ralstonia solanacearum,* as routine screening work using artificial inoculum has been conducted at the same site (Ramathani *et al*., 2018). Furthermore, spores of *Alternaria solani* and *Phytophthora infestans* are usually in the atmosphere, most especially in fields that are continuously used for raising solanaceous crops (Ddamulira *et al*., 2019; Fröhlich-nowoisky *et al*., 2016). Thus, the build-up of inocula and their spread were presumed sufficient and uniformly distributed.

Treatments and design. A total of 45 tomato genotypes (Table 1) were planted. The experiment was laid out in a randomised complete block design, with three replicates.

Experimental management. Plot size was 4 m * 4 m and plant spacing for each genotype was 60 cm within rows and 60 cm between rows. Weeding was done manually at intervals of two weeks. Nimbecidine or Neem oil (Azadirachtin) at a rate of 120 mls per 20 litre Knapsack sprayer was sprayed to control different insect pests within the field, at a two-week interval starting on the day of transplanting, until the end of the study.

Seedlings were raised in the nursery and transplanted after 4 weeks when they were 12 to 15 cm tall, or developed four mature leaves. Poultry manure was used as basal fertiliser at transplanting, at the rate of 250 g per hole, mixed with soil. NPK (17:17:17) was used as top-dressing, four weeks later, at the rate of 20 g per plant.

Experimental materials. The 45 tomato genotypes used in this study (Table 1) were sourced from the World Vegetable Centre in Tanzania, Nongwoo Bio in South Korea, and Advanta in Malawi through collaboration with AATF (African Agricultural Technology Foundation) in Kenya and the local market in Uganda. Genotypes developed by the World Vegetable Centre are inbred lines with different desirable traits. Varieties from Nongwoo Bio and Advanta are commercial lines in South Korea and Malawi, respectively. All of these genotypes were selected based on their diseases resistance attributes (Table 1).

The control genotypes were the commercial varieties commonly found in Uganda and frequently grown by the farmers. These have different attributes that range from disease resistance to long shelf life. The study also included some local lines, namely Red cherry, Yellow cherry, and MT56. The cherries are locally grown in Uganda; however their disease resistance attributes are not yet ascertained, which is why they were included in the study. Makerere Tomato Accession 56 (MT56) was introduced in Uganda from Wooster Breeding Programme, Ohio, USA; and has been cultivated on-farm for quite some time by farmers; and on research stations but is not yet registered in Uganda. MT56 has moderate to high levels of resistance to bacterial wilt in Central Uganda (Asiimwe *et al*., 2013). The agronomic characteristics for the study tomato genotypes are summarised in Table 1.

Postulate test and data collection. *Ralstonia solanacearum* infection was confirmed by the streaming test, followed by culturing the susceptible pathogen on Triphenyl Tetrazolium Chloride (TTC) agar media (Sangoyomi *et al*., 2011). Visual disease ratings, namely incidence and severity of leaves, petioles and stems, were made by examining 10 tagged plants per genotype, by assigning each plant a severity score for the different diseases based on documented scales (Table 2). Data were collected using developed field data notebooks and recorded on the aforementioned diseases on the different tomato varieties for each of the tagged plants.

Data collection. Disease severity data were collected using the documented severity scales on ten tagged plants within each plot (Table 2).

TABLE 1. Tomato genotypes screened for resistance to bacterial diseases at the National Crops Resource Research Institute (NaCRRI), Namulonge in 2019

Line		Source	Resistance attributes
1	AVTO0102		*Bwr12, TMV*
2	AVTO0301		*Bwr12,TMV, TYLCD*
3	AVTO1003		*Bwr12,TMV, TYLCD*
4	AVTO1008		*Bwr12,TMV, TYLCD*
5	AVTO1219		*Bwr12, Ph-2*, *Ph-3,TMV, TYLCD*
6	AVTO1315		*Bwr12, Ph-2*, *Ph-3,TMV, TYLCD, Sm*
7	AVTO1422	World Vegetable Centre, Tanzania	*Bwr12, TMV, TYLCD, Sm*
8	AVTO1424		*Bwr12, TYLCD*
9	AVTO1429		*Bwr12,TMV, TYLCD*
10	AVTO1701		*Ph-2*, *Ph-3, TYLCD, Sm*
11	AVTO9802		*Bwr12,FW,Sm*
12	AVTO0922		*Bwr12,TMV, TYLCD*
13	AVTO1314		*Bwr12,TMV, TYLCD*
14	AVTO1464		*Bwr12TMV, TYLCD*
15	AVTO1418		TMV, *TYLCD, Sm*
16	AVTO1420		TMV, *TYLCD, Sm*
17	AVTO1009		*Bwr12, TYLCD, Sm*
18	Asya616		TMV, *TYLCD, FW*
19	Calliope		TMV, *TYLCD, FW*
20	Eureka		TMV, TSWV, *TYLCD, FW*
21	Pinktop		*TMV*, *FW*
22	Pruna	South Korea	*Bwr12*,TMV
23	Rhino		TMV
24	Tenten		TMV
25	Tygo		TMW,TSWV, TYLCD, FW
26	Zodiac		*TMV, TYLCD ,FW*
27	Vega		*Bwr12, TMW, FW, TYLCD*
28	ADV12021		
29	ADV12073		
30	ADV12076	AATF – Kenya	*Bwr12*
31	ADV1285		
32	ADV1287A		
33	Commando F_1	Commercial variety	*Bwr12, TMV, TYLCD*
34	Money-maker		*FW, VW*
35	Novelle F_1		*Bwr12,* VW, FW
36	Rambo F_1		*Bwr12,*FW, VW, BS
37	Ranger F_1		*Bwr12, TMV, TYLCD, FW*
38	Riogrande		*Ph-2*, *Ph-3,*VW, FW, TMV
39	Roma VFN		VW, FW, N
40	Rionex		VW
41	Tengeru 97		N, TMV, FW
42	Assila F1		TYLCD
43	MT56	USA	*Bwr12*
44	Red cherry	Local germplasm	Not known
45	Yellow cherry		Not known

Bwr12 = Bacterial wilt resistance, *Ph-2*, *Ph-3* = late blight resistance, *VW* = Verticillium wilt resistance, *FW* = Fusarium wilt, *TMV* = Tomato mosaic virus (TMV) resistance, *TYLCD* = Tomato yellow leaf curl virus disease resistance, Sm = Gray leaf spot, TSWV = Tomato spotted wilt virus, BS = Bacterial speck resistance, N = Nematode resistance

TABLE 2. Severity scales adopted for the different diseases as exhibited by the ten tomato genotypes at Namulonge in Uganda

Disease	Scale details	References
Tomato bacterial wilt	1: no symptoms, 2: one leaf wilted, 3: 2 - 3 leaves wilted, 4: 4 or more leaves wilted, 5: plant dead or whole plant wilting	Uwamahoro *et al.*, 2018
Bacterial speck	1: no lesions, 2: 1–10 lesions/ plant, 3: 11–20 lesions/plant, 4: 21–40 lesions/plant, 5: more than 40 lesions/plant	Chambers and Merriman, 1975
Early blight and late blight	0: No symptoms, 1: 1-10% of the total leaf area is blighted, 2: 11-25% of the area of a plant affected, 3: 26-55% of the area of a plant affected, 4: 51-75% of the area of a plant affected, and 5: >75% of the area of a plant affected	Saleem *et al.*, 2016

Disease severity data were used to calculate the area under the disease progress curve (AUDPC), based on the model proposed by Campbell and Madden (1990).

$$AUDPC = \sum_{i=1}^{n-1} \left(\frac{y_i + y_{i+1}}{2} \right) (t_{i+1} - t_i)$$

Where:

n = number of reviews, y = percentage of disease severity and t = time spent with the evaluations, in days.

For each plot, the number of plants showing characteristics symptoms of the disease being scored was noted and used to calculate the percent disease incidence (PDI) (Gomez and Gomez, 1984), using the formula:

$$PDI = \frac{\text{Number of symptomatic plants within the plot}}{\text{Total number of plant within a plot}} * 100$$

Yield data. From the time the first mature fruits (fruits that appear green-yellow or yellow-orange or red) were noticed on ten tagged plants within each plot, harvesting was initiated until plant senescence. The mature fruits were weighed for all harvested rounds and added together to get the yield per plant. Fruit weight per plant was used to approximate the yield per variety.

Data analysis. Analysis of variance was performed with the AUDPC data; and means of genotypes were grouped by the Scott-Knott test at 5% probability, using software Genes (Cruz, 1997). Data for disease incidence were square-root transformed (Gomez and Gomez, 1984). The AUDPC, the transformed incidence and yield data were subjected to analysis of variance, using the GenStat Statistical package 12th edition (VSN International, 2013). Treatment means were separated using Fishers Least Significant Difference (LSD) at $P<0.05$ (Steel *et al.*, 1997).

RESULTS AND DISCUSSION

Tomato varietal reaction

Bacterial wilt infection. Bacterial wilt symptoms were observed as early as the first week after transplanting the various tomato genotypes (Table 1). This explains the high level of tolerance; while Asya616, Rhino, Calliope, Tygo, Eureka, Zodiac, Tenten, Pinktop, Red cherry, Yellow cherry, Riogrande and Roma VFN were susceptible. Roma VFN was also tested by Aslam *et al*., (2017) in Liberia and realised that it was susceptible to *Ralstonia solanacearum* (Tokpah *et al*., 2019).

Genotypes with the highest AUDPC included Riogrande, Assila F_1 and Rionex; while those with the lowest AUDPC were ADV12021, AVTO1314 and Vega. Genotypes with the highest AUDPC were commercial varieties on the market; while those with the lowest AUDPC were new introductions that were not yet released in Uganda (Fig. 1). Similar genotypes with the highest incidence included AVTO1418, Eureka and Rionex; while those with very low incidence included AVTO922, AVTO1464, Pruna, AVTO1701, AVTO1219 and Vega (Table 3).

Based on this screening, genotypes AVTO922, AVTO1464, Pruna, AVTO1219 and Vega had a high tolerance to *Ralstonia solanacearum* (Table 3). These genotypes are known to carry the *Bwr-12* gene that conditions bacterial wilt resistance (Fufa *et al*., 2011). The study further revealed that Pruna and Vega from South Korea and ADV1287A from Malawi were tolerant of bacterial wilt and these too were reported to carry *Ralstonia solanacearum* resistant genes (Fufa*et al*., 2011; Nongwoo bio, 2020). These results imply that we can utilise the above genotypes to transfer the resistance to other popular but susceptible genotypes such as Money-maker through breeding.

Among the local genotypes, MT56 had low AUDPC and PDI values for bacterial wilt. MT56 was bred primarily for bacterial wilt and, thus this study has further proven the resistance stability of MT56 to *Ralstonia solanacearum* (Asiimwe *et al*., 2013; Tusiime *et al*., 2019). The study observed that AVTO1701 has low AUDPC and PDI values, despite not having resistance genes for bacterial wilt. Low AUDPC and PDI could be attributed to the diversity of *Ralstonia solanacearum* isolates (Strain and races) that occur in the field (Alam and Rustgi, 2020).

Tomato bacterial speck. There were significant differences ($P<0.05$) in the AUDPC and PDI of tomato bacterial speck among the genotypes (Fig. 2 and Table 3). Bacterial speck developed steadily for the first five weeks after transplanting, and reached a peak at the 6th week; but suddenly declined to zero (*data not shown*). Bacterial speck was not observed in the second season, despite the conducive conditions of temperature and humidity (rainfall) during the season (Fig. 3).

Among the screened genotypes, 21 showed mild symptoms for *Pseudomonas syringae* pv *tomato* infection (Fig. 3). Despite the low level of disease with the season, Eureka, AVTO1219 and Commando F_1 had the highest AUDPC; while Zodiac, Vega and AVTO9802 had the highest PDI (Table 3). Eureka is reported to carry resistance genes for race 0 (*Pseudomonas syringae* pv *tomato* 0) (Nongwoo bio, 2020); however, this study showed that Eureka was the most affected by *Pseudomonas syringae* pv *tomato* in the field. Two races, 0 and 1 of *Pseudomonas syringae* pv *tomato*, have been reported to date, and the pathogen population structure has gradually shifted from race 0 to race 1 due to the wide use of tomato cultivars carrying the gene Pto for resistance to race 0 (Yuqing *et al*., 2018). This means that probably both races do exist in Uganda and this needs to be validated. For breeding purposes, there is a need to introgress resistance genes for managing both races i.e. Pto or Pto-1 genes from *S. pimpinellifolium* accession PI370093, Pto-2 from *S. pimpinellifolium* accession PI126430, and

Figure 1. Area under the disease progress curve values (AUDPC) for different tomato genotypes under natural bacterial wilt infection at Namulonge in Uganda.

TABLE 3. Percent disease incidence (PDI) for different diseases on different tomato genotypes at Namulonge in Uganda

No.	Variety	Origin	¥Bacterial wilt	¥Bacterial speck	¥Early blight	¥Late blight	Fruit yield (t ha^{-1})
1	Commando F_1	Commercial	76.7b	0.0f	80.0ab	100.0a	18.6
2	Money-maker	Commercial	83.4ab	0.0f	0.0d	82.5ab	-
3	Novelle F_1	Commercial	56.7bc	0.0f	56.7bc	95.9a	26.1
4	Rambo F_1	Commercial	83.4ab	0.0f	35.0c	89.0a	12.4
5	Ranger F_1	Commercial	83.4ab	0.0f	60.0b	95.0a	16.8
6	Riogrande	Commercial	98.0a	0.0f	38.4c	87.5a	1.9
7	Roma VFN	Commercial	65.4b	0.0f	5.0d	100.0a	2.2
8	Rionex	Commercial	100.0a	0.0f	10.0d	95.0a	-
9	Tengeru 97	Commercial	27.7c	0.0f	50.0bc	99.2a	13.1
10	Assila F_1	Commercial	96.6a	0.0f	0.0d	100.0a	-
11	Asya616	Korea	69.7b	0.0f	61.7b	94.2a	-
12	calliope	Korea	75.7b	6.7e	11.3d	100.0a	-
13	Eureka	Korea	100.0a	8.4d	6.3d	100.0a	0.6
14	Pinktop	Korea	85.6ab	5.0e	0.0d	88.3a	-
15	Pruna	Korea	5.0f	0.0f	48.4c	91.7a	17.5
16	Rhino	Korea	96.7a	6.7	6.7d	96.7a	0.5
17	Tenten	Korea	96.7a	0.0f	10.0d	86.7a	-
18	Tygo	Korea	96.7a	6.7e	10.0d	100.0a	0.6
19	Zodiac	Korea	90.5a	26.7a	13.4d	98.8a	1.1
20	Vega	Korea	16.7cd	20.0b	48.4c	100.0a	12
21	MT56	local	33.4c	0.0f	0.7d	100.0a	16.7
22	Red cherry	local	57.3bc	0.0f	25.0cd	78.0b	0.2
23	Yellow cherry	local	53.5bc	0.0f	10.0d	85.0ab	-
24	AVTO0102	Tanzania	51.0bc	0.0f	56.7bc	98.4a	5.8
25	AVTO0301	Tanzania	42.5bc	0.0f	50.0bc	97.5a	29
26	AVTO1003	Tanzania	23.4c	5.0e	53.4bc	100.0a	7.1
27	AVTO1008	Tanzania	48.8bc	0.0f	100.0a	98.4a	-
28	AVTO1219	Tanzania	16.7cd	6.7e	86.7a	83.0ab	12
29	AVTO1315	Tanzania	23.4c	0.0f	60.0b	88.4ab	30.8
30	AVTO1422	Tanzania	33.4c	0.0f	60.0b	96.7a	10.5
31	AVTO1424	Tanzania	50.0bc	5.0e	63.4b	82.5b	13.2
32	AVTO1429	Tanzania	23.4c	0.0f	50.0bc	99.2a	16.2
33	AVTO1701	Tanzania	16.7cd	0.0f	63.4b	80.0b	20.9
34	AVTO9802	Tanzania	52.7bc	10.0c	30.0c	100.0a	5.4
35	AVTO0922	Tanzania	15.0cd	0.0f	0.0d	100.0a	-
36	AVTO1314	Tanzania	96.7a	0.0f	6.7d	100.0a	-
37	AVTO1464	Tanzania	16.7cd	0.0f	0.0d	100.0a	-
38	AVTO1418	Tanzania	100a	0.0f	6.7d	100.0a	-
39	AVTO1420	Tanzania	86.7ab	0.0f	13.3d	100.0a	-
40	AVTO9801	Tanzania	33.3c	0.0f	30.0c	100.0a	-
41	ADV12021	Malawi	18.3cd	0.0f	65.0b	94.4a	1
42	ADV12073	Malawi	40.0bc	0.0f	80.0ab	93.4a	11.7
43	ADV12076	Malawi	27.5c	0.0f	91.7a	76.7b	5.6
44	ADV1285	Malawi	92.0a	0.0f	85.0a	92.5a	2
45	ADV1287A	Malawi	40.0bc	0.0f	88.4a	83.0ab	20.1

¥means followed by the same letter are not significantly different from each other at $P<0.05$

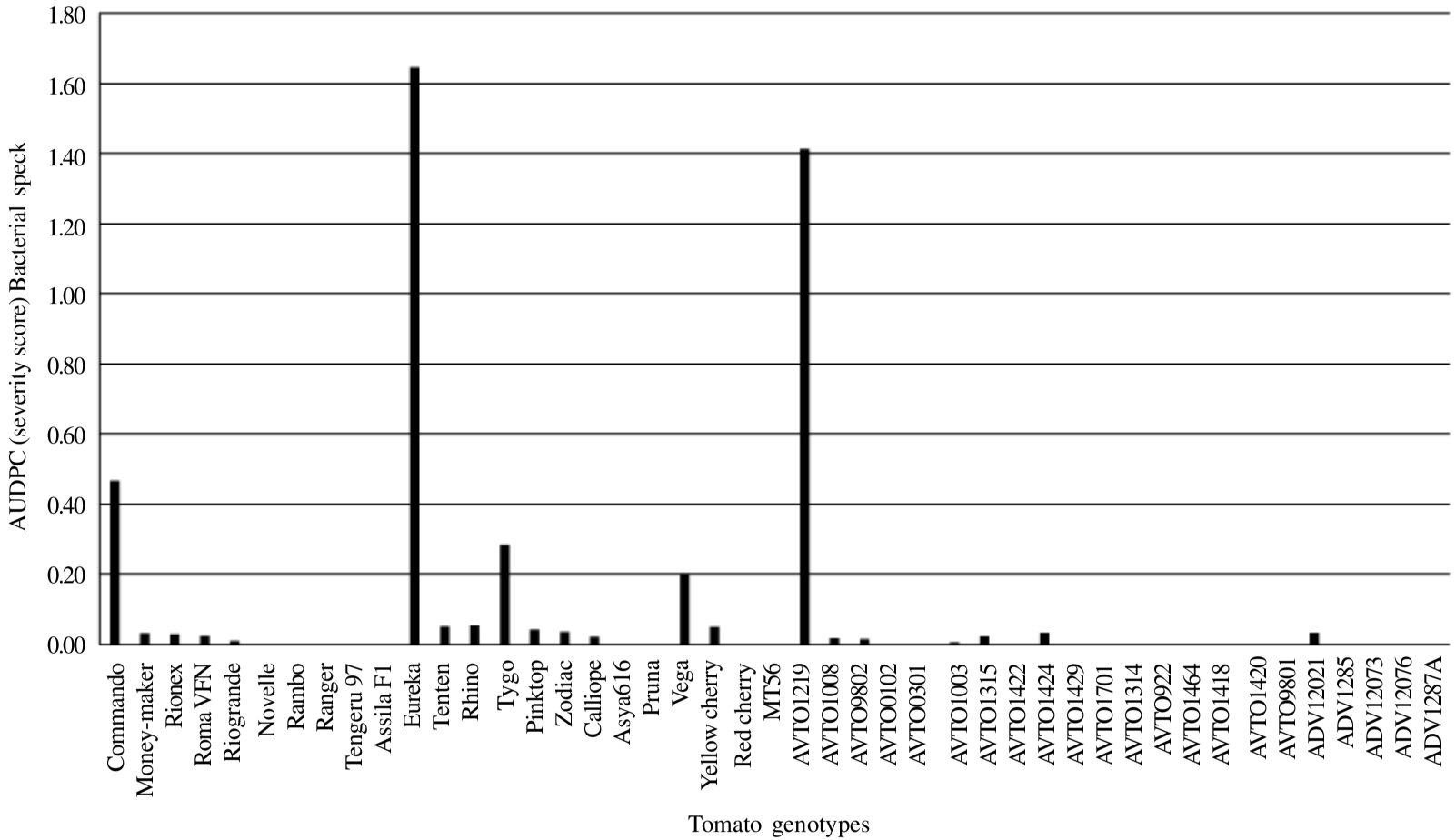

Figure 2. Bacterial speck area under the disease progress curve values (AUDPC) for different tomato genotypes at Namulonge in Uganda.

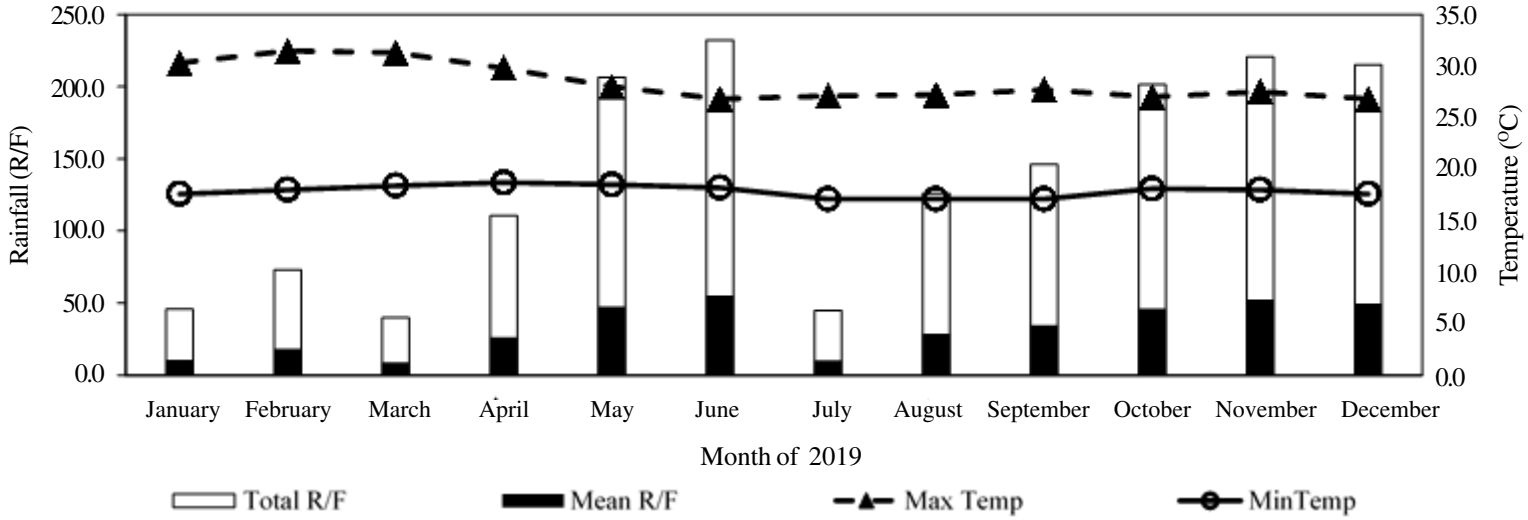

Figure 3. Total and mean rainfall, and the maximum and minimum temperature at Namulonge, in Uganda. Source: Namulonge Meteorological sub-station data for 2019.

Pto-3 from *S. habrochaites* accession PI134417 conferring resistance to race 0 and Pto-4 gene from PI134417conferring resistance to race 1 (Yang and Francis, 2007).

Early blight. There was a significant (P<0.001) difference in reaction of the different tomato genotypes to natural early blight infection (Fig. 4). Early blight was first detected at 14 days after transplanting for 13 out of 45 genotypes under screening. A similar trend was observed at 21 days after transplanting. However, by the end of 49 days after transplanting, AVTO1008 and AVTO1429 had the highest AUDPC value for early blight (Fig. 4). Generally, early blight severity was low among the genotypes; with a mean score of <, 2.0 expressed by all genotypes. Nevertheless, some genotypes, including, Vega, AVTO922, AVTO1464, AVTO1418 and AVTO9801, AVTO1314 AVTO1420, and Assila F_1 had the lowest AUDPC values (Fig. 4). AVTO1008, ADV12076, and ADV1287A had the highest PDI; while Rhino, AVTO1418, Eureka, Roma VFN, MT56, Pinktop, Asila F_1, Money-maker, AVTO0922 and AVTO1464 had the lowest PDI values (Table 3). The low PDI values expressed by the fore-mentioned genotypes indicate a strong resistance conferred by the presence of a source of genes resistant to early blight. Therefore, these lines can be used as donor parents of resistance against virulent strains of *Alternaria solani.*

The two local genotypes, Red and Yellow cherry expressed low PDI values (<25.0%) thus indicating a high level of tolerance to *Alternaria solani* (Table 3). Cherry tomatoes are domesticated wild tomato lines (species *S. habrochaites, S. pimpinellifolium* and *S. peruvianum*) that are known to be highly resistant to *Alternaria solani* and *Phytophthora infestans,* both *in vitro* and under field conditions (Majid *et al.*, 2008; Mahantesha *et al.*, 2012). These results suggests these can be used in breeding programmes for early blight. Furthermore, Pinktop, Asila F1, Money-maker, AVTO0922 and AVTO1464 can also be used as donor parents; however, it had been observed that resistance to *Alternaria solani* is associated with undesirable traits of low yield and late maturity (Adhikari *et al.*, 2017).

Late blight. Late blight was observed one week after transplanting; and by the 14th day, the majority of the genotypes had shown symptoms, except for 5 genotypes (ADV1287A, AVTO1219, AVTO9802, Rambo F_1 and Red cherry). All the 45 genotypes showed some symptoms of late blight, with AUDPC values ranging from 160.48 for Money-maker, and to as low as 28.62 and 29.38 for AVTO1219 and AVTO1701, respectively (Fig. 5). The PDI values ranged from as high as 100% for 16 genotypes and to as low as 76.7% for ADV12076 (Table 3). The high AUDPC and PDI for late blight were attributed to the favourable weather conditions at Namulonge (Figs. 3 and 5). The daily minimum and maximum temperatures were 15 to 27 ºC and 100-240 mm rainfall, all of which provided a conducive environment for the proliferation of *Phytophthora infestans* spores in the field (Agrios, 2005).

Genotypes AVTO1701, AVTO1315 and AVTO1219 were highly tolerant to *Phytophthora infestans* (Fig. 5), a condition that may be attributed to possession of *Ph-2, Ph-3* genes by these genotypes, that condition for resistances to T1,3 and T1,2 *Phytophthora infestans* isolates (Fufa *et al.*, 2011). However, genotypes ADV2021, ADV1287A and ADV12076, though not reported to carry these genes, were also found to have a high tolerance to *Phytophthora infestans;* suggesting the presence of these resistance genes in their genome.

Genotypes ADV1285 and ADV1287A had the lowest incidence; while the majority (71%) of the genotypes had incidences of over 90% (Table 3). The low incidence values among these genotypes could be attributed to the possibility that ADV1285 and ADV1287A possess the *Ph-1* gene (*not yet known*), comparable to the *Ph-2* and *Ph-3* genes found

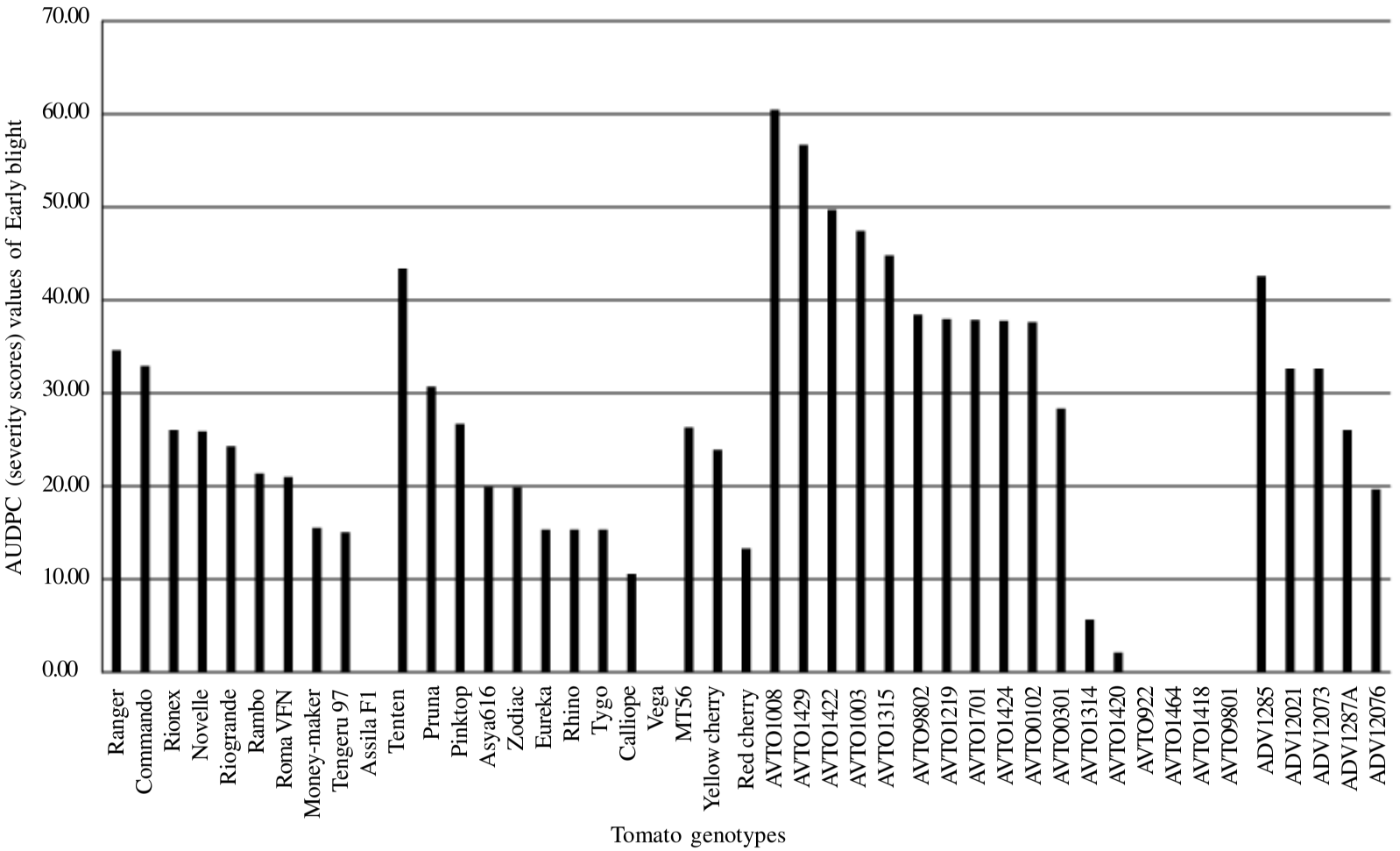

Figure 4. Early blight area under diseases progress curve values (AUDPC) for different tomato genotypes at Namulonge in Uganda.

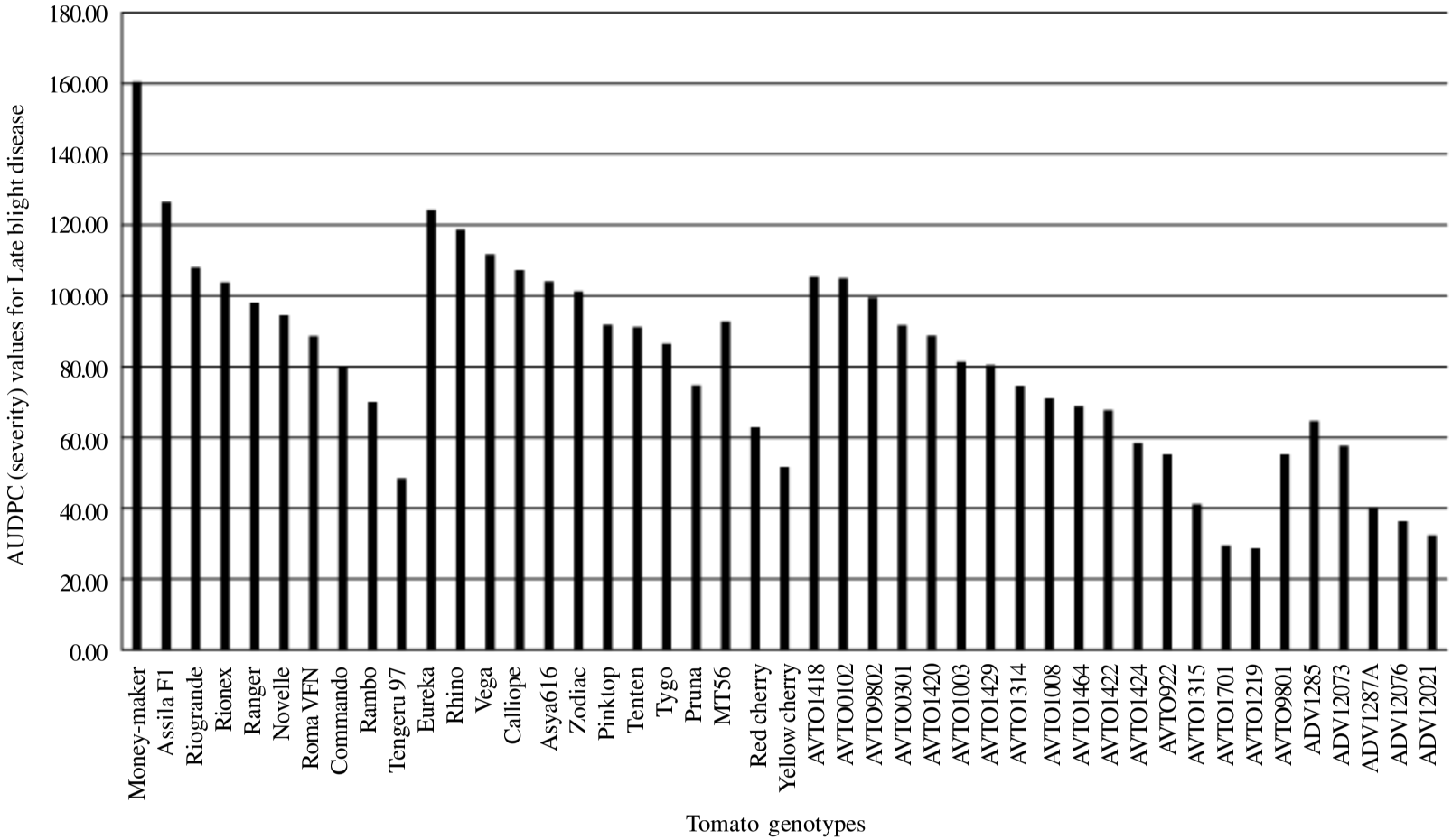

Figure 5. Late blight area under diseases progress curve values (AUDPC) for different tomato genotypes at Namulonge in Uganda.

TABLE 4. Ranking tomato genotypes based on their reaction to major diseases (severity score) and yield performance at Namulonge in 2019

No.	Variety	BW-R	EB-R	LB-R	BS-R	Y-R	R	OR
1	AVTO1701	2	17	1	1	4	25	1
2	Novelle F_1	3	13	11	1	3	31	2
3	AVTO1315	6	16	4	6	1	33	3
4	Pruna	1	18	9	1	7	36	4
5	ADV1287A	1	26	4	1	5	37	5
6	AVTO0922	1	1	5	1	31	39	6
7	AVTO1464	1	1	8	1	31	42	7
8	AVTO0301	19	9	13	1	2	44	8
9	MT56	13	14	7	1	9	44	9
10	CommandoF_1	7	20	11	1	6	45	10
11	Tengeru 97	6	12	14	1	12	45	11
12	AVTO1219	1	24	1	5	14	45	12
13	Vega	5	1	19	8	14	47	13
14	Yellow cherry	3	7	5	1	31	47	14
15	Ranger F_1	9	19	12	1	8	49	15
16	ADV12073	1	29	6	1	15	52	16
17	AVTO1422	8	20	7	1	16	52	17
18	AVTO1429	17	16	10	1	10	54	18
19	Red cherry	15	7	2	1	30	55	19
20	AVTO1003	4	21	11	3	17	56	20
21	AVTO1009	12	6	7	1	31	57	21
22	ADV12076	10	25	3	1	19	58	22
23	AVTO1314	11	5	10	1	31	58	23
24	ADV12021	1	28	2	1	27	59	24
25	Money-maker	23	1	6	1	31	62	25
26	Tygo	18	4	11	2	28	63	26
27	AVTO1424	20	20	6	7	11	64	27
28	AVTO1420	21	3	12	1	31	68	28
29	Rambo F_1	25	18	12	1	13	69	29
30	Asya616	22	11	16	1	21	71	30
31	AVTO0102	14	22	18	1	18	73	31
32	Zodiac	24	8	14	4	26	76	32
33	Rhino	26	2	18	2	29	77	33
34	Pinktop	32	1	10	3	31	77	34
35	AVTO1418	28	2	18	1	31	80	35
36	Calliope	27	10	17	2	25	81	36
37	Roma VFN	25	22	11	1	23	82	37
38	AVTO1008	16	27	7	1	31	82	38
39	AssilaF_1	29	1	21	1	31	83	39
40	Eureka	31	4	20	4	28	87	40
41	ADV1285	30	30	6	1	22	89	41
42	Tenten	34	13	10	1	31	89	42
43	Riogrande	35	18	15	1	24	93	43
44	Rionex	33	15	14	1	31	94	44
45	AVTO9802	36	23	16	5	20	100	45

BW-R = ranking bacterial wilt, ER-R = ranking early blight, LB-R = ranking late blight, BS-R = ranking bacterial speck, Y-R = ranking yield, OR = Overall ranking

in AVTO1219, AVTO1315 and AVTO1701. Akhtar *et al*. (2016) reported similar findings when they tested different tomato genotypes carrying different *Ph*-genes for late blight resistance. Their findings revealed that genotypes having *Ph-1* gene (New Yorker and Rockinghum) were less symptomatic for late blight, compared to those that possessed the *Ph-2* gene (West Virginia and Flora-Dade) and *Ph-3* gene (TMS1), individually as well as in combination (CLN324H-27, CLN3241Q and CLN3241R). *Ph*-2 and *Ph*-3 genes are frequently used by breeders to jointly provide strong resistance to *Phytophthora infestans* (Wang *et al*., 2016). However, this study and others (Irzhansky and Cohen, 2006; Akhtar *et al*., 2016) have proved that the combination of these genes is not supreme against the local *P.infestans* isolates in Uganda. This suggests the need to test genotypes with the *Ph-1* gene alone, as well as in combination with other genes against the local *P. infestans* isolates in Uganda.

Yield performance. Among the 45 genotypes, ten genotypes yielded >15 t ha^{-1} (Table 3). Similarly, the same genotypes ranked high as the most tolerant to the targeted pathogens (Table 4). Yields of field tomatoes are dependent on the location where they are grown, the growing season (weather), the genetic make-up and the field crop management (Heuvelink and Dorais, 2005). It is known that climatic conditions in the tropics favour the survival of numerous pathogens and these significantly compromise the yield of newly introduced or bred tomato cultivars (Huat *et al*., 2013). It was observed that genotypes with high tolerance to Early blight (AVTO1464 and AVTO0922) yielded lower than the average yield (10-14 t ha^{-1}) currently obtained by the farmers in Uganda (Table 3) (Ssekyewa, 2006). The results indicated a negative correlation (Y=-0.5202X +27.274, R^2=0.2163) between fruit yield and early blight PDI value. It has been reported that cultivars with early blight resistance are low yielders and take longer to mature (Maiero *et al*., 2019). With improved disease management and adequate plant population, it is possible to increase tomato yields in Uganda to as high as 40 to 100 t ha^{-1}, depending on their genetic potential (Heuvelink and Dorais, 2005).

Ranking the genotypes. AVTO1701 ranked the best in its tolerance to *Ralstonia solanacearum*, *Pseudomonas syringae* pv. *tomato*, *Alternaria solani* and *Phytophthora infestans;* as well as having high yields. Among the newly introduced genotypes, AVTO1315, AVTO1701, AVTO0922, AVTO1464 and AVTO0301 from the World vegetable centre, Pruna from South Korea, ADV1287A from Malawi and MT56 bred by Makerere University. Nouvelle F_1 and Commando F_1 were the best commercial varieties in terms of their tolerance to the fore-mentioned pathogens and having high yields. Therefore, it can be concluded that none of the 45 tomato genotypes was found to have complete resistance to Bacterial wilt, Bacterial speck, Late blight and early blight. This indicates that there is a need to develop tomato varieties with multiple resistance to several pathogens. Among the screened genotypes, sources of resistance to the targeted pathogens have been identified and through gene pyramiding, high yielding genotypes with multiple resistance can be developed by plant breeders through cross-breeding (Hulbert *et al*., 2001; Baliyan and Rao, 2013).

CONCLUSION

This study has revealed a wide variation in the reaction of tomato genotypes to *Ralstonia solanacearum*, *Pseudomonas syringae* pv. *tomato*, *Alternaria solani* and *Phytophthora infestans*. The results of this study indicate that AVTO1701 is the best yielding and disease tolerant genotypes, followed by Nouvelle F_1 a commercial variety. AVTO1701 is a new candidate line that is not yet released in Uganda, therefore, farmers cannot access the

seed. However, Nouvelle F_1 variety can be accessed from the market though it is relatively expensive (US$ 12 per 5 g of seed) for smallholder farmers. It was concluded that none of the 45 tomato genotypes had complete resistance or tolerance to bacterial wilt, bacterial speck, late blight and early blight. The study revealed that genotypes with a high level of tolerance to early blight (AVTO0922 and AVTO1464) had low fruit yields. Among the commercial varieties screened, Nouvelle F_1 and Commando F_1 should be promoted among the farmers as the best performers in terms of yield and tolerance to diseases. Genotypes AVTO1701, AVTO0922, AVTO1464, AVTO0301 AVTO1315, AVTO1219, Pruna, Vega, ADV1287A and MT56 are recommended for the National Performance Trials (NPTs). Furthermore, the national agriculture research platform is recommended to utilise the new genotypes in the breeding programme.

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