International Journal of Vegetable Science, 16:134–147, 2010

ISSN: 1931-5260 print / 1931-5279 online
DOI: 10.1080/19315260903340040

Development and Release of Late Blight-Resistant Tomato Varieties 'Meru' and 'Kiboko'

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Late blight caused by *Phytophthora infestans* (Mont.) De Bary is among the most economically important diseases of tomato. The use of host–plant resistance offers a potentially cost-effective and environmentally sound complementary disease management strategy for incorporation into tomato late blight integrated pest management (IPM). Late blight resistance in tomato (*Solanum lycopersicum* L.) was derived from *S. pimpinellifolium* and introgressed into highland-adapted tomato already resistant to *Fusarium* wilt, root-knot nematodes, tomato mosaic virus (ToMV) and tomato yellow leaf curl virus (TYLCV). Evaluation and selection for durability of late blight resistance, yield, and other horticultural traits was done in a controlled environment at AVRDC, The World Vegetable Center headquarters in Shanhua, Taiwan, and under field conditions at the Regional Center for Africa in Arusha, Tanzania. Four lines were subjected to multilocational trials with a local check at 5 sites representing 4 agroecological zones. Two of the best performing lines with enduring resistance to late blight, LBR19-2 and LBR44-2, were released as new varieties in Tanzania under trade names 'Meru' and 'Kiboko' in 2007 and 2008, respectively.

Keywords Solanum lycopersicon, Phytophthora infestans, Host–plant resistance, Late blight, Tanzania.

The development and evaluation of the late blight–resistant tomato lines were carried out under BMZ/GTZ Funded Project No 99.7860.2-001.00, Contract No. 81035823. Multilocational trials and release of the late blight–resistant lines in Tanzania were funded by DANIDA Agricultural Sector Support Programme Contract No. 1/2004 and Alpha Seed Company, Arusha, Tanzania. The authors acknowledge technical support of P. Ngwediagi (Ministry of Agriculture, Cooperatives and Food Security), E. Meela (MARTI, Uyole, Mbeya), L. Mrosso (Makutopora Viticulture Research Center, Dodoma), A. Goha (Cholima Agriculture Research Institute Dakawa Morogoro), and A. Mulwafu (Seatonadale Research Station, Iringa).

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INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is among the most widely cultivated vegetable crops in sub-Saharan Africa, grown for fresh market and sometimes for processing. Tomato is susceptible to many pests and diseases. Late blight caused by *Phytophthora infestans* (Mont.) De Bary is among the most devastating foliar and fruit diseases of tomato in the highlands of sub-Saharan Africa (Sengooba and Hakiza, 1999). Late blight infections can occur during any stage of tomato crop development, causing complete or partial crop loss.

Late blight may quickly destroy foliage, stems, and fruit of tomato plants if weather conditions favor the pathogen, causing heavy yield losses if no control measures are applied (Tumwine et al., 2002a). Losses vary, depending on prevailing weather conditions, management practices, and presence of other tomato diseases (Asian Vegetable Research and Development Center [AVRDC], 2003). Farmers can lose the entire crop if timely application of fungicides is not done. In surveys conducted between 1997 and 1999, Tanzanian tomato farmers and producers ranked late blight as the worst among pests and diseases of tomato (Swai and Slumpa, 2005). In a 2006 survey, 93.5% of respondents indicated that late blight was the most destructive disease affecting tomato production in Tanzania (Maerere et al., 2006). In Uganda, the disease was identified as a major constraint to tomato production along with problems associated with heavy pesticide use in major tomato production areas (Tumwine et al., 2002b). In Kenya, late blight ranks among the top constraints of tomato production; together, late blight and early blight [*Alternaria solani* (Ell. and Mart.) Jones and Grout] account for 95.8% of all the preharvest losses of tomato (Waiganjo et al., 2006).

Generally, application of fungicides has been the only reliable control for late blight. Disease management strategies primarily depend on sanitary practices and well-timed fungicide applications based on favorable weather conditions, because decision support systems often are lacking in many developing countries (Fry and Godwin, 1997). Use of chemicals to control late blight in tomato increases production costs of up to 20% (Mizubuti, 2005). Emergence or predominance of resistant *P. infestans* strains necessitates use of increased quantities of fungicide or the substitution of cheaper fungicides by more expensive ones, raising production costs further (Reis et al., 2005). In Kenya, the highest pesticide use during tomato production is for control of early and late blights, with up to 40 applications per crop season (Waiganjo et al., 2006).

Besides posing possible health hazards from residues on tomato produced for the fresh market or for processing, extensive fungicide application pollutes water, air, and soil; drift affects nontarget microorganisms. The development of fungicide resistance within populations of *P. infestans* has become a major problem in many tomato-growing regions (Fry and Godwin, 1997). Effective fungicides are too expensive for many tomato farmers in the developing world, most of whom are resource poor. Alternative approaches that can be incorporated into integrated pest management (IPM) strategies for control of tomato late blight disease are needed. Host–plant resistance is potentially the most economically viable, technically feasible, environmentally friendly, and socially acceptable disease management strategy for tomato late blight IPM. This project was undertaken to develop tomato lines with resistance to late blight.

MATERIALS AND METHODS

Development, Evaluation, and Selection of Late Blight–Resistant Tomato Lines

Late blight resistance derived from *S. pimpinellifolium* accession L3708 was introgressed into highland-adapted tomato lines (coded ARP) already resistant to *Fusarium* wilt, root-knot nematode, and tomato mosaic virus (ToMV; AVRDC, 1996). From August to December 1997, F_2 plants were sequentially screened for resistance to race 2 of the *Fusarium* wilt pathogen and a race T1,2 isolate of the late blight pathogen at AVRDC, the World Vegetable Center in Shanhua, Taiwan (AVRDC, 1998). Tomato seeds were sown in 72-cell speedling trays (Speedling, Sun City, Fla.) containing Cornell soil mix (Boodley and Sheldrake, 1973). Seedlings with 2–3 true leaves were transplanted to 15-cm-diameter clay pots containing Cornell soil mix. Plants were grown in a greenhouse at 25°C with a daily 16-h light period and fertigated after 3–5 days with 15N–2.2P–12.5K water-soluble fertilizer (Peters 15-5-15; The Scotts Co., Marysville, Ohio). Plants were staked to prevent contact with the ground and spread of the disease. Fungicides were not applied. The foliage of 35-day-old seedlings was sprayed until runoff with the zoospore/sporangia suspension (5×10^4 sporangia·mL^{-1}) by using a spray gun (1.6 kg/cm^2 pressure). Inoculated plants were incubated for 24 h at 100% RH and 20 ± 2°C without light. Thereafter, plants were maintained at 60–95% RH and 20 ± 2°C with 14-h light per day (70 $\mu Em^2 \cdot s^{-1}$). Disease severity rating was done at 10 days after inoculation based on 0–6 disease scales.

The F_2 plants resistant to both diseases were transplanted to the field and selection was carried out for good fruit set and quality. A randomized complete block design (RCBD) with 3 replications was used. Plots were two 20-cm-high beds centers with one row per bed. Spacing was 40 cm between plants within rows and 1.5 m between beds. Beds were covered by gray plastic mulch and rice straw. Plants were staked but not pruned. A basal application of 120N–52P–100K–32 Mg kg·ha^{-1} and an additional 90N–38P–74K–24 Mg kg·ha^{-1} was applied over 4 side dressings. Pesticides were used to control insects and furrow irrigation was applied as needed. Three plants were selected at random in each plot and the total number of clusters, flowers per cluster, and fruit set per cluster were counted. Fruit set was expressed as number of fruit, or enlarged pedicels, divided by flower number. The F_3 lines were harvested from single F_2 plants with high fruit set and screened for ToMV in 1998 (AVRDC, 1999). The F_4 lines were harvested from individual F_3 plants resistant to ToMV. Forty-nine F_4 lines of CLN 2256, CLN2260, and CLN2264 (crosses between *S. pimpinellifolium* accession L 3708 and ARP tomato lines) were evaluated for horticultural traits including days to 50% flowering, number of flowers per cluster, percentage fruit set, fruit shape, fruit weight, and seed yield from August to December 1998 in Taiwan. Seeds of 44 F_5 lines were provided to AVRDC's Regional Center for Africa at Arusha, Tanzania, for further screening and selection for late blight resistance under severe natural disease pressure. The 44 F_5 lines were screened from February to June 1999 at the Regional Center for Africa's Experimental Research Farm in Arusha, Tanzania, and the codes late blight resistant (LBR) adopted.

From July to November 1999, 16 F_6 lines were evaluated for yield. Seeds were sown in July 1999 and seedlings transplanted in two-row, 6-m-long, plots with rows spaced 75 cm apart and 50 cm between plants. The experiments were laid out in an RCBD with 3 replications. Fertilizer (100 $kg{\cdot}ha^{-1}$ NPK, 20-10-10) was applied during transplanting. An additional 50 $kg{\cdot}ha^{-1}$ of N as urea was applied as a top dress 3, 5, and 7 weeks later. Furrow irrigation occurred twice weekly after transplanting until harvest. The field was kept weed free throughout the growing season. Staking was 2 weeks after transplanting. Lateral buds were pruned once. The trial was repeated in 2000 with 14 F_6 selections sown on 17 Feb. 2000 and evaluated for yield. Seedlings were transplanted on 24 Mar. 2000 with the experimental layout described above and evaluated for field resistance to late blight.

From the two F_6 trials, a total of 114 single plant selections were made based on horticultural traits; seed of each F_7 line was sent to AVRDC headquarters and screened for late blight resistance under controlled greenhouse conditions using a T1,2 isolate as described for F_2 above. The same F_7 lines were evaluated in the field in Arusha, Tanzania. Seed was harvested from 28 F_7 plants selected for late blight resistance, bulked, and the 15 most promising F_8 lines were evaluated for horticultural characteristics with 'Tengeru 97', 'Marglobe', and 'Moneymaker' serving as checks. The F_8 seedlings were transplanted on 3 Sept. 2001 in an RCBD with 3 replications and the experiment conducted as described for F_6 lines. The F_9 seed from 5 promising F_8 lines were harvested, bulked, and sown in December 2001 for further evaluation.

The performance of 10 selected F_{10} lines from the F_9 selections was compared to determine yield potential and other horticultural traits during the rainy season. 'Tengeru 97' and 'Marglobe' were included as checks. The experiment was conducted at Arusha from April to September 2002. The experimental layout and management practices were as described above. Seeds of the best 4 lines were bulked and used for multilocational variety testing.

Multilocational Testing of LBR Tomato Lines

From 2004 to 2006, 15 trials were conducted in 5 locations in Tanzania: the Horticultural Research and Training Institute Tengeru (HORTI Tengeru) at Arusha (1260 masl; 3°22′S, 36°41′E); Cholima AgroScientific Research Institute at Dakawa, Morogoro (550 masl; 6°49′S, 37°40′E); Makutupora Viticulture Research and Training Institute in Dodoma (1290 masl; 6°11′S, 35°45′E); Seatondale Agricultural Research Sub Station in Iringa (1630 masl; 7°46′S, 35°42′E); and the Ministry of Agriculture Research and Training Institute (MARTI), Uyole in Mbeya (1860 masl; 8°54′S, 33°27′E).

Mbeya and Iringa represented cool, wet highland areas. Temperatures in these two areas ranged from –6°C in the highlands to 29°C in the lowlands. The weather from June until November is dry and cold, whereas it is relatively wet and warm from December to April. The rainfall is unimodal and the rainfall averages about 1100 $mm \cdot yr^{-1}$; the rainy season is from December to April. Dodoma is located in a cool, dry, medium-altitude area characterized by a long dry season lasting from late April to early December and a short single wet season occurring from January to March. The rainfall is unimodal and the average rainfall per year is 570 $mm \cdot yr^{-1}$. Temperature in the region varies according to altitude, with an average minimum of 18°C and average maximum of 31°C. Arusha is a cool, wet, medium-altitude area. The average max/min temperatures vary with altitude between 12 and 27°C, with June and July being the coldest months. The rainfall is bimodal with a mean annual rainfall of 800 mm. The main rainy period is from March to May. Morogoro is a hot, low-altitude area. Annual rainfall is approximately 900 mm with a bimodal pattern: the "long rains" fall between March and May, and the "short rains" fall during October and November.

Trials consisted of the LBR indeterminate tomato lines LBR19-2, LBR19-3, LBR44-2, and LBR50-2 developed, evaluated, and selected on the basis of stability of the resistance, high yield, and positive horticultural traits, together with cv. Tengeru 97 as a standard check. Trials were arranged in an RCBD with 3 replications. Plot size at all locations, in all years, was 6 m long and 1 m wide, consisting of two rows. For each plot, rows were 75 cm apart and seedlings were established with an in-row spacing of 50 cm between plants. Data were collected from 20 inner plants, with the 4 outer plants serving as guards.

Seedlings were transplanted 4–6 weeks after sowing. Plants were staked and side shoots removed to leave two vines. For each region, cultural practices and insect pest management were carried out as detailed for F_6 on-station trials. However, in Mbeya phosphorus was applied at planting as triple superphosphate (20 $kg \cdot ha^{-1}$ P_2O_5), whereas 200 $kg \cdot ha^{-1}$ nitrogen was applied in 3 split of urea applications, starting 3 weeks after transplanting. Abamectin (Seneria Industries

Table 1: Some chemical and physical soil characteristics of experimental sites in different locations.

Soil characteristic	Arusha	Dodoma	Morogoro	Iringa	Mbeya
Organic carbon (%)	1.40	0.90	1.45	2.40	1.90
Total N (%)	0.21	0.08	0.11	0.16	0.06
Available P ($\mu g \cdot g^{-1}$)	40.25	38.79	56.63	29.3	24.8
Exchangeable potassium (cmol (+)·kg $soil^{-1}$)	1.43	1.11	0.54	0.22	
Exchangeable magnesium (cmol (+)·kg $soil^{-1}$)	2.85	2.39	4.13	1.17	10.20
Exchangeable calcium (cmol (+)·kg $soil^{-1}$)	8.05	4.07	6.07	0.92	
Soil pH ($CaCl_2$)	5.90	5.20	5.60	4.80	5.00
CEC (cmol (+)·kg $soil^{-1}$)	16.50	12.8	15.4	22.24	16.6
Textural class	Clay[a]	SCL	SCL	Clay	SL

[a]SCL = sandy, clay loam; SL = sandy loam.

Ltd., Limassol, Cyprus) and Karate (Sulphur Mills Ltd., Mumbai, India) were used for control of mites and insects, respectively. Two trials were established in each location. In one trial the fungicide Ridomil Mz (Syngenta Crop Protection, Basle, Switzerland) was applied when first symptoms of late blight were observed; the other trial was conducted without fungicides. There were differences in soil characteristics of trial sites (Table 1).

RESULTS AND DISCUSSION

Evaluation and Selection of LBR Tomato Lines

From 49 F_4 lines evaluated at the Regional Center for Africa in Arusha, Tanzania, 44 F_5 plants with the best fruit set and quality were selected (AVRDC, 2000). When evaluated for late blight resistance, the F_5 selections expressed various levels of resistance to late blight throughout the evaluation process (Table 2). Evaluation of F_6 selections from selected resistant F_5 rows for fruit yield characteristics in two separate experiments from July to November 1999 and from February to June 2000 (Table 3) resulted in 114 new F_7 selections. Of the 114 F_7 selections screened for late blight resistance in Taiwan under controlled greenhouse conditions using a T1,2 isolate as described in the Materials and Methods, 90 selections were resistant. The remaining 24 selections were segregating or were susceptible (AVRDC, 2001). Of the lines tested under field conditions in Arusha, 28 were resistant to late blight and the 15 most promising F_8 lines were bulked (AVRDC, 2002). The remaining lines were susceptible or segregating. All single selections found resistant in Arusha were among the 90 selections resistant to late blight under controlled conditions at AVRDC in Taiwan.

Table 2: Late blight incidence and severity of F_5 tomato lines evaluated in the field at AVRDC Regional Center for Africa, Madira Farm, February–June 1999.

Line code	Previous code	Incidence[a]	Severity[b]
LBR 17-1	CLN 2264-4-4-14	90 a[c]	4.16 b
LBR 23-1	CLN 2264-4-8-18	90 a	3.94 bc
LBR 38-1	CLN 2264-4-67-1	18.11 efghi	0.20 hi
LBR 20-1	CLN 2264-4-7-19	90 a	4.22 b
LBR 20-2	CLN 2264-4-7-19	90 a	3.74 bcd
LBR 20-3	CLN 2264-4-7-19	77.84 a	3.63 bcd
LBR 20-4	CLN 2264-4-7-19	85.27 a	3.69 bcd
LBR 20-5	CLN 2264-4-7-19	90 a	3.11 de
LBR 20-6	CLN 2264-4-7-19	90 a	4.19 b
LBR 20-7	CLN 2264-4-7-19	90 a	3.36 cde
LBR 20-8	CLN 2264-4-7-19	90 a	4.30 b
LBR 35-3	CLN 2264-4-31-2	27.4 defg	0.29 hi
LBR 26-2	CLN 2264-4-16-18	23.21 efg	0.24 hi
LBR 26-3	CLN 2264-4-16-18	50.53 bc	1.84 f
LBR 10-1	CLN 2260-3-52-19	15.76 efghi	0.15 hi
LBR 10-2	CLN 2260-3-52-19	0.00 i	0.00 l
LBR 10-3	CLN 2260-3-52-19	16.39 efghi	0.24 hi
LBR 10-4	CLN 2260-3-52-19	16.36 efghi	0.13 hi
LBR 9-1	CLN 2260-3-52-17	30.84 def	0.32 hi
LBR 9-3	CLN 2260-3-52-17	15.19 efghi	0.05 i
LBR 8-2	CLN 2260-3-3-27-7	6.45 hi	0.07 i
LBR 7-2	CLN 2260-3-27-2	90 a	3.09 de
LBR 42-1	CLN 2264-4-70-6	0.00 i	0.00 i
LBR 45-1	CLN 2264-4-82-12	9.55 ghi	0.07 hi
LBR 45-3	CLN 2264-4-82-12	5.82 hi	0.02 i
LBR 45-4	CLN 2264-4-82-12	6.14 hi	0.03 i
LBR 7-1	CLN 2260-3-27-2	90 a	3.26 cde
LBR 3-1	CLN 2256-2-70-11	16.71 efghi	0.12 hi
LBR 3.3	CLN 2256-2-70-11	5.11 hi	0.02 i
LBR 32-2	CLN 2264-4-30-19	19.87 efghi	0.14 hi
LBR 28-1	CLN 2264-4-22-11	43.45 bcd	0.88 gh
LBR 28-2	CLN 2264-4-22-11	55.99 b	1.45 fg
LBR 28-3	CLN 2264-4-22-11	9.78 ghi	0.04 i
LBR 28-4	CLN 2264-4-22-11	56.89 b	1.26 fg
LBR 1-6	CLN 2260-3-52-19	6.14 hi	0.06 i
LBR 29-1	CLN 2264-4-22-12	19.09 efghi	0.15 hi
LBR 29-2	CLN 2264-4-22-12	76.92 a	2.64 e
LBR 29-3	CLN 2264-4-22-12	11.57 fghi	0.06 i
LBR 29-4	CLN 2264-4-22-12	16.22 efghi	0.17 hi
LBR 29-5	CLN 2264-4-22-12	90 a	4.25 b
LBR 29-6	CLN 2264-4-22-12	9.03 ghi	0.03 i
LBR 30-1	CLN 2264-4-22-19	14.72 fghi	0.10 hi
LBR 30-2	CLN 2264-4-22-19	82.40 a	3.39 cde
LBR 30-3	CLN 2264-4-22-19	35.19 cde	0.77 ghi
Moneymaker	Moneymaker	90 a	6 a
CV%		23.6	26.3

[a]Incidence data recorded 63 days after transplanting; values were transformed by arcsine before analysis of variance.
[b]Disease severity ratings made 63 days after transplanting on a 0–6 scale, where 0 = no symptoms and 6 = 91%–100% leaf area affected and/or dead plants.
[c]Values in a column followed by the same letter are not significantly different, $P \leq 0.05$, Duncan's multiple range test.

Table 3: Yield factors of late blight–resistant F_6 tomato lines evaluated in Arusha, Tanzania, 1999 and 2000.

1999 F_6 evaluation trial					2000 F_6 evaluation trial				
Line code	No. fruits/plant	Fruit weight (g/fruit)	Yield (kg/plant)	Yield ($Mt \cdot ha^{-1}$)	Line code	No. fruits/plant	Fruit weight (g/fruit)	Yield (kg/plant)	Yield ($Mt \cdot ha^{-1}$)
LBR 3-1	31 ab[a]	74.2 c	2.3 ab	54.26 ab	LBR 8-2	34 bcdef	58.8 c	2.0 ab	47 ab
LBR 3-3	42 a	54.8 g	2.3 ab	55.06 ab	LBR 9-1	40 bcd	45.0 d	1.8 abc	42 abc
LBR 32-2	43 ab	39.5 h	1.7 bc	40.46 bc	LBR 9-3	61 a	37.7 de	2.3 a	55 a
LBR 28-1	31 ab	64.5 e	2.0 bc	47.20 bc	LBR 10-1	40 bcd	50.0 cd	2.0 ab	47 ab
LBR 28-2	31 ab	61.2 f	1.9 bc	45.83 bc	LBR 10-2	43 bc	41.9 d	1.8 abc	42 abc
LBR 28-3	30 ab	66.7 de	2.0 bc	49.06 bc	LBR 10-3	44 ab	43.2 d	1.9 ab	46 ab
LBR 28-4	22 b	77.3 bc	1.7 bc	40.43 bc	LBR 10-6	46 b	39.1 de	1.8 abc	43 abc
LBR 1-6	35 ab	62.8 ef	2.2 ab	53.60 ab	LBR 20-5	36 bcde	38.9 de	1.4 bcd	33 bcd
LBR 29-1	26 b	53.8 g	1.4 c	33.66 c	LBR 26-2	28 def	46.4 d	1.3 bcd	30 bcd
LBR 29-2	28 b	64.3 e	1.8 bc	42.03 bc	LBR 26-3	27 def	55.6 c	1.5 bcd	36 bcd
LBR 29-3	24 b	75.0 c	1.8 bc	42.80 bc	LBR 35-3	23 ef	39.1 de	0.9 d	22 d
LBR 29-4	24 b	83.3 a	2.0 bc	47.50 bc	LBR 38-1	30 cdef	50.0 cd	1.5 bcd	35 bcd
LBR 29-6	27 b	70.4 d	1.9 bc	45.36 bc	LBR 42-1	21 ef	57.1 c	1.2 bcd	29 bcd
LBR 30-1	26 b	69.2 d	1.8 bc	42.26 bc	LBR 45-3	10 f	110.0 a	1.1 bcd	28 cd
LBR 30-2	24 b	79.2 b	1.9 bc	45.63 bc	Marglobe	22 ef	90.9 b	2.0 ab	48 ab
LBR 30-3	26 b	65.4 e	1.7 bc	40.46 bc					
Tengeru 97[b]	33 ab	84.8 a	2.8 a	66.86 a					
CV%	21.9	8.2	18.0	18.0	CV%	23.0	10.4	24.0	24.0

[a]Values in a column followed by the same letter are not significantly different, $P \leq 0.05$, Duncan's multiple range test.
[b]Tengeru 97 included as a local check variety.

Of the 15 new F_8 selections tested under field conditions in Arusha, yield of the lines, LBR19, LBR44, LBR50, LBR80, and LBR81, were comparable to, or better than, commercial check varieties (Table 4). Within each line there was segregation for growth habits and further single plant selection was performed to increase uniformity. The F_9 seed was harvested from single plant selections from the 5 promising lines and 10 F_{10} lines were evaluated for yield and other horticultural traits (AVRDC, 2003). Among the F_{10} late blight–resistant lines tested, 'LBR44-2', 'LBR19-2', 'LBR19-3', and 'LBR50-2' produced fruit yields of 120.5, 107.2, 101.3, and 96.8 $Mt{\cdot}ha^{-1}$, respectively, that were significantly higher than other late blight–resistant lines (Table 4). 'Marglobe' and 'Tengeru 97' were affected by late blight, leading to total crop loss. Seed of the above 4 LBR lines were bulked and used for multilocational variety testing.

Multilocational Testing and Release of LBR Tomato Varieties

Dry conditions in Dodoma, and warm conditions in Morogoro, did not favor late blight disease occurrence and severity. Even the susceptible check, 'Tengeru 97', did not show disease incidence (Table 5). Over years, conditions were not severe in Iringa and Arusha; even the susceptible check showed only moderate severity. The most favorable conditions for late blight disease occurrence were in Mbeya, where the disease incidence was 100% and severity was 6 for the susceptible check during the 3 years of trials. The LBR lines showed enduring resistance at all locations throughout the 3-year period, and reduction of yields in some locations was caused by other factors.

The 4 lines yielded significantly higher than 'Tengeru 97', especially when planted during the wet seasons in hot-spot areas without fungicide protection (Figure 1) The yield of the check variety at the late blight–infested area of Mbeya was 0 $Mt{\cdot}ha^{-1}$ in each of the 3 years without fungicide application. Yields of the LBR lines ranged from 3.3 to 11, 4.5 to 8, and 19 to 26 $Mt{\cdot}ha^{-1}$ in 2004, 2005, and 2006, respectively (Figure 1A–1C). Fungicide application did not improve the situation much because the yields of the susceptible check were only 0.2, 3.1, and 2.2 $Mt{\cdot}ha^{-1}$ in 2004, 2005, and 2006, respectively. Yields of the LBR lines ranged from 14–23, 6–11, and 7–16 $Mt{\cdot}ha^{-1}$ in 2004, 2005, and 2006, respectively. These yields were still generally low, considering the general potential yields of fresh market tomato in Tanzania. This was partly due to other diseases, such as early blight and cold-related physiological disorders.

To underscore the importance of late blight disease, the marketable yields of the susceptible check was comparable to, or sometimes higher, than the LBR lines with or without fungicide application in Dodoma where there was no disease incidence. Yield of 'Tengeru 97' were 118, 112, and 50.9 $Mt{\cdot}ha^{-1}$ with fungicide application and 104, 92, and 48.5 Mt ha^{-1} without fungicide

Table 4: Yield factors of late blight resistant F_8 and F_{10} tomato lines evaluated in Arusha, Tanzania, in 2001 and 2002.

2001 F_8 evaluation trial					2002 F_{10} evaluation trial				
Line/variety	**No. fruits/plant**	**Fruit weight (g/fruit)**	**Fruit yield (kg/plant)**	**Fruit yield ($Mt{\cdot}ha^{-1}$)**	**Line/ variety**	**No. fruits/plant**	**Fruit weight (g/fruit)**	**Fruit yield (kg/plant)**	**Fruit yield ($Mt{\cdot}ha^{-1}$)**
LBR 19	24 bc[a]	137.1 b	3.30 a	88 a	LBR 19-2	30 abc	139.7 ab	4.09 ab	107.2 ab
LBR 29	22 cd	83.4 ef	1.83 efghi	48.8 efghi	LBR 19-3	29 abc	130.8 ab	3.80 bc	101.3 bc
LBR 38	24 bc	82.7 efg	2.00cdefg	53.4 cdefg	LBR44-1	21 de	140.7 ab	2.76 bc	71.9 de
LBR 39	26 b	66.4 fgh	1.74 fghi	46.3 fghi	LBR44-2	35 a	127.9 abc	4.52 a	120.5 a
LBR 40	13 f	111.3 cd	1.47 ghi	39.3ghi	LBR44-3	16 e	149.3 a	2.31 e	61.3 cd
LBR 41	21 de	97.9 cde	2.12 bcdefg	56.6 bcdefg	LBR44-4	21 de	124.5 abc	2.54 de	66.7 de
LBR 42	21 de	95.3 de	1.98 cdefg	52.7 cdefg	LBR44-5	24 cd	123.1 abc	3.00 de	79.9 de
LBR 44	22 cd	111.3 cd	2.45 bcde	65.3 bcde	LBR50-2	27 bcd	138.5 ab	3.68 bc	96.8 bc
LBR 50	27 b	104.0 cd	2.80 ab	74.7 ab	LBR80-5	33 ab	102.0 c	3.24 cd	85.3 cd
LBR 58	19 e	64.6 h	1.20 i	32.1 i	LBR81-3	25 cd	118.4 bc	2.95 de	77.3 de
LBR 80	24 bc	113.8 c	2.73 ab	72.7 ab	Tengeru 97	0 f	0 d	0 f	0 f
LBR 81	23 cd	114.5 c	2.64 bc	70.3 bc	Marglobe	0 f	0 d	0 f	0 f
LBR 91	20 de	65.1 gh	1.27 hi	33.8 hi					
LBR 94	31 a	72.0 fgh	2.23 bcdef	59.4 bcdef					
LBR 110	23 cd	83.0 efg	1.89 defgh	50.4 defgh					
Marglobe[b]	17 e	156.0 a	2.57 bcd	68.6 bcd					
Tengeru 97	25 bc	100.1 cd	2.51 bcde	67 bcde					
Money Maker	32 a	75.0 fgh	2.37 bcdef	63.2 bcdef					
CV (%)	19.2	15.8	15.9	15.9	CV (%)	18.1	13.9	13.7	13.7

[a]Values in a column followed by the same letter are not significantly different, $P \leq 0.05$, Duncan's multiple range test.
[b]Marglobe, Moneymaker, and Tengeru 97 included as local check varieties.

Table 5: Reaction of late blight–resistant tomato lines to late blight in different locations from 2004 to 2006.

	Arusha			Dodoma			Mbeya			Iringa			Morogoro		
Line no.	**2004**	**2005**	**2006**	**2004**	**2005**	**2006**	**2004**	**2005**	**2006**	**2004**	**2005**	**2006**	**2004**	**2005**	**2006**
LBR19-2	R[a]	R	R	R	R	R	R	R	R	R	R	R	R	R	R
LBR19-3	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
LBR44-2	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
LBR50-2	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Tengeru 97[b]	S	MR	MR	R	R	R	S	S	S	MR	S	MR	R	R	R

[a]Based on disease severity rating (DSR) scale of 1–6 (AVRDC, 1998). Highly resistant (R) = DSR 0–2.5; moderately resistant (MR) DSR 2.6–4.5; susceptible (S) = DSR 4.6–6.0. 0 = No symptoms; 1 = <5% of leaf area affected with restricted lesions; 2 = 6%–15% of leaf area affected with no deep stem lesions; 3 = 16%–30% of leaf area affected with no deep stem lesions; 4 = 31%–60% of leaf area affected with few small stem lesions; 5 = 61%–90% of leaf area affected with expanding stem lesions; 6 = 91%–100% of leaf area affected with extensive stem lesions or whole plant death.
[b]Tengeru 97 included as a local check variety.

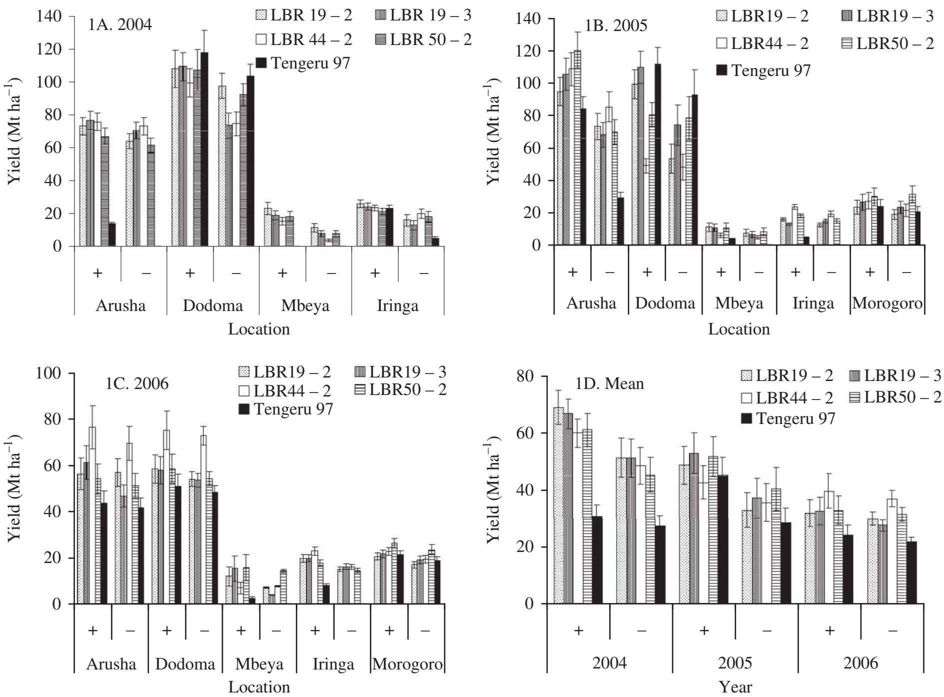

Figure 1: Marketable fruit yields (Mt·ha^{-1}) of late blight-resistant tomato lines treated with (+) and without (–) fungicide application in 4 locations in 2004 (A) and 5 locations in 2005 (B) and 2006 (C). Mean yields of tomato in the 3 years are shown in Figure 1D. Bars = standard error.

application in 2004, 2005, and 2006, respectively. Yields of LBR lines treated with fungicides ranged from 99 to 109, 49 to 110, and 59 to 75 Mt·ha^{-1} and without fungicides were 73–98, 48–78, 54–72 Mt·ha^{-1} in 2004, 2005, and 2006, respectively.

When fungicides were applied once in 3 weeks during the rainy season, mean yield increase of the LBR lines above the check across 5 locations ranged from 19% to 42%, 7% to 17%, and 31% to 64% in 2004, 2005, and 2006, respectively. Without fungicide application, mean yield increase of LBR lines above the check, across 5 locations, ranged from 65% to 88%, 16% to 42%, and 27% to 70% in 2004, 2005, and 2006, respectively (Figure 1D).

The marketable fruit yield performance in the southern highlands was lower when compared to the yields from the northern highlands and Dodoma. In the southern highlands, early blight is a major limitation of tomato production and the relatively lower yields of the 4 LBR lines in Mbeya and Iringa were partly due to early blight damage. There were also high rates of cat-facing in Mbeya, a physiological disorder characterized by misshapen fruit with large scars and cavities in the blossom end with streaks and bands of scaly, dark greenish and tan scar tissue between swellings (AVRDC, 2004). Mbeya is very cool in the second half of the year and cat-facing is associated with prolonged cool weather when plants are young, causing abnormal development of the flower bud before blossoming. In Morogoro, a low-elevation area, low yield was largely due to severe whitefly (*Bemisia tabaci* Genn.) infestation, resulting in high incidence of begomovirus infection. The best yields were obtained in the Dodoma highlands where weather is cool and generally dry, resulting in lower incidence of diseases, insect pests, and other physiological disorders.

At all trial sites, LBR19-2 and LBR44-2 were the most promising when all traits were considered, with stable late blight resistance. Farmer participatory variety evaluations and selection involving crop and fruit observation and organoleptic tests confirmed that the two lines were the most appealing to farmers and consumers; positive attributes included fruit firmness, fruit shape, transportability, marketability, and tolerance to diseases (Swai et al., 2008). In December 2007 the Tanzanian National Variety Release Committee released F_{12} of LBR19-2 under the name 'Meru'; in December 2008 F_{12} of LBR44-2 was released under the name 'Kiboko'. In collaboration with the private sector, regional research institutes, and non-governmental organizations (NGOs) efforts are being carried out to start sustainable production and commercialization of these two varieties in East and Southern Africa.

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