

SELECTION OF LATE BLIGHT RESISTANT VARIETIES IN BANGLADESH FROM CIP POPULATION B3 POTATO CLONES

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ABSTRACT: Bangladesh is in a subtropical monsoon region and extends from 20°34'N to 26°38'N latitude, its agriculture is comprised of several diversified rice-based cropping systems. Potato is an important winter crop across the country. To help increase the sustainability of potato production in Bangladesh, a set of medium-term late blight-resistant potato clones bred in CIP were evaluated for diversification potential at six locations from 2008 to 2013. After seven years of field trials, TCRC, BARI identified two clones, namely CIP 393371.58 (coded LB-6) and CIP 393280.64 (LB-7) which are consistently resistant to Late Blight under field conditions without fungicide and yield as well or better than the predominant commercial varieties (Diamant) in a 90-day cropping window. According to the AUDPC, LB-4, LB-5, LB-6 and LB-7 were moderate to highly resistant to Late Blight. The latter two produced over 30 tons of tubers per hectare. Similar yields were recorded in on-farm trials during 2011-12. These two clones were entered into regional yield trials as a requirement for variety release by the NSB. Based on field performance at on-station and farmers' fields, NSB released BARI Alu-46 (LB-7) in 2013 and BARI Alu-53 (LB-6) in 2014 as the country's two late blight-resistant varieties.

KEYWORDS: Potato; late blight resistance; earliness

ABBREVIATIONS:

LB: Late blight
CIP: International Potato Center
TCRC: Tuber Crops Research Centre
BARI: Bangladesh Agricultural Research Institute
AEZ: Agro-Ecological Zone
NSB: National Seed Board
AUDPC: Area under the disease progress curve
PYT: Preliminary Yield Trial
SYT: Secondary Yield Trial
AYT: Advanced Yield Trial
RYT: Regional Yield Trial
DUS: Distinctness, Uniformity, and Stability

INTRODUCTION

Bangladesh's agriculture is predominantly based on smallholdings with about 80% of the farmers cultivating less than one hectare, Land preparation is transitioning from the use of draft animals and hand tools to the use of small machinery such as power tillers. Intensive cropping patterns help to satisfy the increasing food and other demands of the country's rising population on agriculture, and innovations take cropping patterns into account. The improvement of varieties for intensive cropping patterns requires a combined approach of early-stage selection for disease resistance, adaptation to

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temperature, photoperiod, soil, and related factors as for monoculture, followed by validation trials under farm conditions for measuring yield potential under multiple stresses, and eventually evaluating total system performance (Francis and Smith, 1985).

As an increasingly important part of several diverse and complex cropping systems, potato (*Solanum tuberosum* L.) is the third most important food crop in Bangladesh, after paddy rice and wheat. It is an increasingly successful cash crop, with unit yield and gross return higher than other winter crops and second only to that of paddy rice. (<https://www.potatopro.com/bangladesh/potato-statistics>). Bangladesh ranks 8th in world potato production and 3rd in Asia (FAOSTAT, 2018). Over the past two decades, the country's potato production grew from 1.55 Mt to 9.47 Mt, on the area that expanded from 0.136 to 0.47 M ha.; with recent yields ranging from 18.1 to 20.41 t/ha (FAOSTAT, 2018). The country needs 0.76 Mt of seed potatoes for total potato production, whereas government organizations can supply only 5% quality seed potatoes (BADC, 2022).

The lack of short-season disease-resistant potato varieties, lack of timely seed supply and inefficient market systems persist as major constraints to enhancing productivity and profitability of the crop (Kadian *et al.*, 2009; Singha and Maezawa, 2019). Despite concerted national and international research and development efforts to improve potato production, the crop is challenged by edaphic-climatic adversities (drought, heat, and salinity) and by diseases caused by viral, bacterial, and fungus-like pathogens such as the causal agent of potato late blight.

Late blight (LB), caused by the Oomycete *Phytophthora infestans*, occurs regularly in

the Indo-Gangetic Plains of Bangladesh and West Bengal, India) where it causes yield loss ranging from 25 to 60% (Khan *et al.*, 1989; Ali and Dey, 1998). Severity depends upon the susceptibility of the variety, the aggressiveness of local pathogen populations, the effectiveness of complementary control methods and the prevailing environmental factors (Dey *et al.*, 1995; Hossain *et al.*, 2002). Deployment of resistant varieties is the best option against late blight, but in the absence of these, Bangladeshi farmers apply upward of 7-8 sprays per season at the cost of about 13500-15000 Tk./ha or 5-6% of the total production cost (Haque *et al.*, 2012). *P. infestans* has displayed large flexibility in its adjustment to a changing environment. The appearance of new populations and races of *P. infestans* has been associated with the breakdown of resistance. This necessitates the search for resources with effective resistance to predominant forms of the pathogen; In tandem with the characterization of the pathogen, the evaluation of germplasm for resistance to Late Blight has turned out to be a regular activity worldwide (Kaushik *et al.*, 2007; Wulff *et al.*, 2007). One way to identify durable resistance in potato genotypes is to assess them in time (two or more seasons testing at a location) or spatially (in several locations and in large plots) or a combination of these (Cotes *et al.*, 2002).

Toward the development of medium maturing, late blight resistant cultivars, the Tuber Crops Research Centre (TCRC) introduced advanced bred lines from the International Potato Center (CIP) in Peru in 2008 and these were evaluated for seven years following standard evaluation procedures (Rashid *et al.*, 1987; BARI 2009; BARI 2015; Kundu *et al.*, 2013; Kundu *et al.*, 2018). Here, we report on the advanced stages of clonal evaluation to identify suitable short-season, late blight-resistant potato varieties for rice-

based systems of Bangladesh and validate farmers' and consumers' acceptance and the on-farm performance of two recently released varieties.

MATERIALS AND METHODS

Plant Material

A set of 12 advanced potato clones bred by CIP were evaluated at Bogura, Munshiganj, and Jamalpur during 2008-09, 2009-10, and 2010-11 under a collaborative project supported by GTZ, Germany (Table 1).

All test clones were from recurrent selection cycles 1 or 2 (C1 or C2) of CIP's Population B3 bred in Peru for table quality, yield and disease resistance (Lindqvist-Kreuze

et al., 2014). Each selection cycle consisted of evaluation over 4 years in 4 subtropical lowland and tropical highland environments with and without exposure to high levels of endemic pressure from late blight. They were further assessed for resistance to three virus diseases by intentional exposure to PLRV, PVX and PVY. The clones were transferred to Bangladesh as in vitro plantlets under the terms of a Material Transfer Agreement (https://research.cip.cgiar.org/cipcatlg_ac/Catalogue.php?). Upon introduction to Bangladesh through TCRC, the plantlets were acclimated to screen house conditions and grown out to produce tuber seed. Hereafter, the term F_1 is used to denote the clones' hybrid constitution and the terms C_1 , C_2 , C_3 ,

Table 1. Key characters of potato clones used in the variety testing program during 2008-2013

CIP No.	TCRC code	Key characters	Population cycle	Resistance traits
CIP 391004.18	LB 1	White-Cream skin, Pale yellow tuber flesh color, Long-oblong tuber shape, shallow eye depth	B3C1	Late Blight
CIP 391046.14	LB 2	White cream skin, yellow flesh color, oblong shape with shallow eye depth.	B3C1	Late Blight, PVX (ER) and PVY (ER)
CIP 391058.175	LB 3	White cream skin, yellow flesh color, oblong-flattened tuber shape with shallow eye depth.	B3C1	Late Blight
CIP 393077.159	LB 4	White cream skin, cream flesh color, oblong- tuber shape with shallow eye depth.	B3C1	Late Blight and PVX (ER)
CIP 393085.5	LB 5	White cream skin, cream flesh color, oblong- tuber shape with shallow eye depth.	B3C1	Late Blight, PVX (ER) and PVY (ER)
CIP 393280.64	LB 6	Red skin, oblong tuber shape and pale-yellow flesh with superficial eyes, medium to large tuber sizes, high tuber number per plant with wide range of adaptation.	B3C1	Late Blight PVX and PLRV
CIP 393371.58	LB 7	Crème skin color with pink eyes, oblong tuber shape, cream flesh with superficial eyes, medium to large tuber sizes, High yield under LB disease.	B3C1	late blight and PVX (ER)
CIP 395011.2	LB 8	White cream skin, cream flesh color, oblong- tuber shape with shallow eye depth.	B3C2	Resistant to Late Blight PVX (ER) and PVY(ER)
CIP 396004.337	LB 9	White cream skin, cream flesh color, oblong- tuber shape with shallow eye depth.	B3C2	Resistant to Late Blight
CIP 396031.108	LB 11	White cream skin, cream flesh color, oblong- tuber shape with shallow eye depth.	B3C2	Resistant to Late Blight
CIP 396031.119	LB 12	Pink skin, pale yellow flesh color, oblong- tuber shape with shallow eye depth.	B3C2	Resistant to Late Blight
CIP 396031.119	LB 14	White cream skin, cream flesh color, oblong- tuber shape with shallow eye depth.	B3C2	Resistant to Late Blight

ER- extreme resistance (After: Catalogue of Advanced Clones (cgiar.org), (https://research.cip.cgiar.org/cipcatlg_ac/Catalogue.php?))

etc. refer to cycles of clonal propagation for successive evaluation trials after recovery from in vitro conditions. Selections were carried out based on foliage type, tuber yield, tuber qualities and LB infection.

Field Trials (2008-2013)

Trial Management

A series of on-station and on-farm trials were conducted in 6 agro-ecological zones (AEZ) of Bangladesh to evaluate 12 advanced bred clones from CIP and validate the acceptance and performance of two that were recommended and released as varieties. The series of activities conducted for potato variety testing, release, and recommendation by BARI is illustrated in Figure 1.

All field trials ranging from preliminary, secondary, advanced, and regional yield trials (PYT, SYT, AYT and RYT) were conducted on research stations of TCRC in 3m × 3m plots. The on-station trials in each location

were replicated thrice with a row spacing of 60 cm and plant spacing of 25 cm, The F_1C_1 and F_1C_2 clonal generations were evaluated in PYT and SYT, respectively, at three trial sites, namely, Jamalpur, Bogura, and Munshiganj. Clones in F_1C_3 and F_1C_4 were evaluated under AYT in 4 trial sites and RYT at six trial sites namely, Rangpur (AEZ 2), Bogura (AEZ 4), Jamalpur (AEZ 8), Jashore (AEZ 11) Munshiganj (AEZ 16) and Joydebpur (AEZ 28) (FRG, 2018). Additionally, in 2011-12, farmers' field trials were conducted in Bogura (3) Jamalpur (3) and Cumilla (3) to validate and compare the on-station yield of the two most promising clones with the yield in farmer's field conditions. In RYT, plots were harvested at 2 stages, at 65 days to measure the earliness of tuber bulking and at 90 days. Varietal performance was validated through on-farm, adaptive trials after the release of two of the clones as new varieties. This validation was performed across 250 trials at 12 locations under the Potato-Rice-

The scheme of potato variety evaluation/development protocol is presented in Fig. 1.

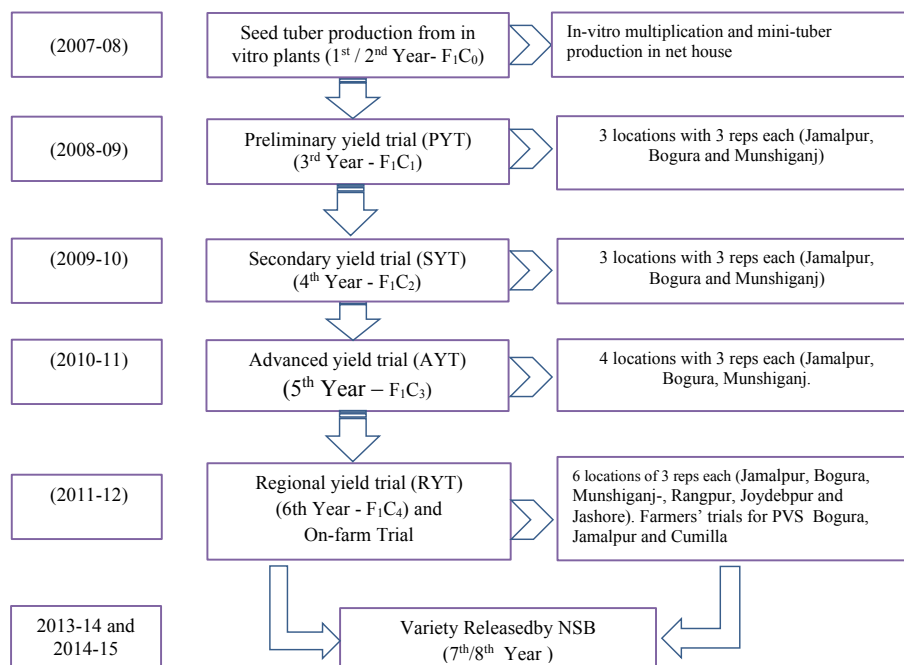


Fig. 1 Activities followed in LB resistant potato Variety Development by TCRC, Bangladesh

Rice system during 2015-16. Disease-free seed tubers were supplied to the farmers, who were then responsible for all aspects of management. The potato plots were harvested at 90 DAP with the attendance of scientists and farmers. Participatory assessment of farmer's preferences was conducted through consultation on Late blight resistance, plant appearance, marketability and overall acceptability.

In RYT, data were collected on morphological and tuber characteristics, yield at 65 and 90 DAP (t/ha), tuber dry matter (%) and post-harvest behavior in ambient conditions were compiled and submitted to National Seed Board (NSB) to recommend the top-performing two clones for variety release.

Agronomic management

Properly sprouted un-cut seed potatoes were sown on 15 November and 20 December each year, at 1500 kg/ha. Before planting, seed tubers of each genotype were treated with carbendazim (0.1%). Crops were fertilized according to the fertilizer recommendation guide (FRG, 2018). The crops were irrigated four times. Light irrigation was applied at 8–10 DAP for proper emergence of the tubers; the 2nd and 3rd irrigations were applied at 30–35 and 45–50 DAP reaching 2/3rd of the furrow depth. Finally, after 60–65 DAP, light irrigation was also applied. Two hands weeding were done before the 2nd (at 30–35 DAP) and 3rd (60–65 DAP) irrigations. Carbofuran (Furadan 5G®, Padma Oil Company Limited, Bangladesh) was applied @ 500 g a.i./ha during land preparation to control cutworms and Imidacloprid (Admire 20 SL®, Bayer Crop Science Limited, Bangladesh) was sprayed @ 25 g a.i./ha at 45 and 60 DAP to control aphid vectors of potato viruses. No fungicides were applied to protect the test clones from late blight. Crops

were dehaulmed at 80 DAP and harvested after 10 days' curing (90 DAP.)

Assessment of Quality Parameters

Tuber dry matter:

Dry matter (DM) estimation was performed from five randomly collected tubers of the 90-day harvest per plot in the RYT trials using fraction samples of 150 g fresh weight (dried in an oven for 72 hours at 80 °C until a constant weight was attained) (Gupta *et al.*, 2015). Final DM content was estimated by the following formula:

$$\text{Tuber dry matter (\%)} = \frac{\text{Sample dry weight} \times 100}{\text{Sample fresh weight}}$$

Keeping quality: Thirty tubers (ten each of large, medium and small size) of each genotype were stored in net boxes at ambient temperature. Weight loss and rottage were recorded at 15-day intervals up to 90 days after harvest.

Measurement of Late Blight susceptibility

The percent of leaf area affected by *Phytophthora infestans* was recorded on a plot basis at 7-day intervals and averaged across reps before being used to calculate AUDPC according to the formula of 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 "t" is the time of each reading, "y" is the percentage of affected foliage at each reading and "n" is the number of readings. The AUDPC was calculated using Data Collector from CIP (<https://research.cip.cgiar.org/confluence/display/GDET4RT/Downloads>).

The clones were classified as highly resistant (AUDPC < 250), resistant (251-350), moderately resistant (351-650), susceptible

(65-1200) and highly susceptible (AUDPC >1200) when the susceptible control showed more than 90% late blight infection as per **Gopal and Singh (2003)**.

Virus disease incidence (PVY and PLRV) was determined by regular observation of the plants in the field trials, where the PVY and PLRV infected plants were recorded. The incidence of the two viruses was expressed in the percentage of plants with symptoms.

Statistical Analysis

Total tuber yield (t/ha) (PYT, SYT and AYT) was used in a combined analysis of variance (ANOVA) to ascertain the contributions of genotype (G), environment (E) and their interaction (G×E) to the variation observed. Morphological and tuber parameters; yield at 65 and 90 DAP; tuber dry matter (%), keeping quality in ambient conditions were observed in RYT and the DUS test were recorded according to the format prescribed by the National Seed Board (NSB). Tuber yield was collected from an area of 3.6 m² (1.2 m × 3 m) in each of the locations and converted into t/ha. AUDPC data in successive generations (PYT, AYT and RYT) were also used in combined ANOVA to determine the contributions of genotype

(G), environment (E) and their interaction. Tuber yield (t/ha) data was collected from on-farm trials.

RESULTS

Climatic conditions of the trial sites

Meteorological data on minimum (night) and maximum (day) temperature (°C) during the potato growing seasons are presented in Fig. 2. Temperatures declined slightly from November to January and then increased gradually. The monthly average maximum temperature ranged from 23.4 to 36.0°C across the locations, with the lowest value in Rangpur (the northern part of Bangladesh) in January and the highest temperature in Munshiganj in March. Similarly, the monthly average minimum night temperature ranged from 10.7 to 23°C across the different trial sites, with the minimum in Rangpur in January and the maximum in Munshiganj in March.

Tuber yield in successive generations (PYT, SYT, AYT and RYT) and in on-farm trials

Potato genotypes grown in different agro-ecological zones showed considerable variation in tuber yield (Table 3). Genotype (G), environment (E) and genotype × environment interaction (G × E) were highly

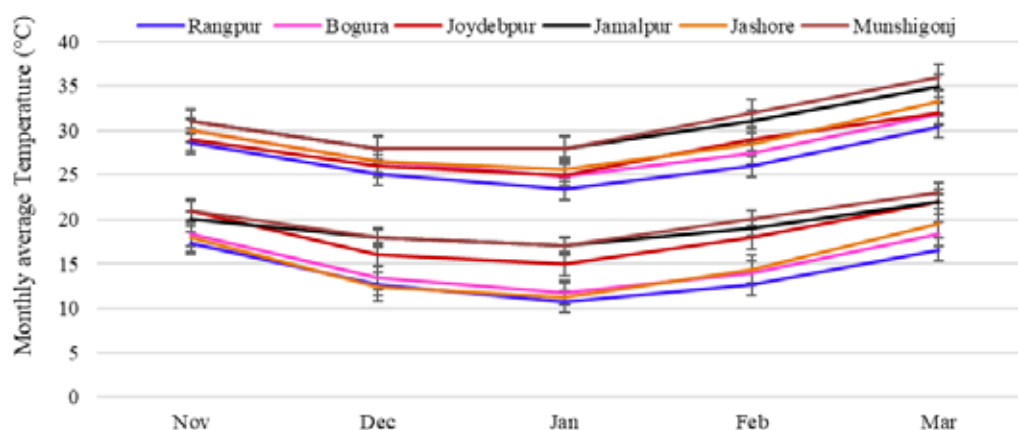


Fig. 2 Average air temperature °C (Max. and min.) in different trial sites during the crop growth period (2008-2012)

significant ($p < 0.001$) (Table 2). The highly significant $G \times E$ impacts suggest that potato genotypes may need to be cautiously chosen for an adjustment to specific environments.

In the PYT, selection considered the mean yield at 90 DAP across three locations, tuber shape, size, skin color, late blight resistance and overall appearance. Significant variation in yield was observed. The highest average yield was 27.00 t/ha for LB-7, closely followed by LB 8 (26.9 t/ha), LB-5 (24.70 t/ha), LB-4 (23.70 t/ha) and LB-6 (22.90 t/ha). The mean AUDPC for late blight in PYT was the highest

in Diamant, followed by LB-2, LB-1, LB-9 and LB-12. Considering AUDPC, only LB-5, LB-6, and LB-7 showed moderate resistance to the disease (Table 3). Considering all selection criteria, 7 clones were advanced to the secondary yield trial (SYT).

The SYT was conducted at 3 trial sites (Bogura, Jamalpur and Munshiganj) (Table 2). Significant variation in yield was observed. LB 7 produced the highest average yield (38.59 t/ha) at 90 DAP. The lowest yield was in LB-6, the average being 27.78 t/ha, whereas the check variety Diamant yielded

Table 2. Average total tuber yield at 90 DAP for genotypes and environments in PYT, SYT and AYT

Factor	Genotype	Yield (t/ha) at 90 DAP		
		PYT (2008-09)	SYT (2009-10)	AYT (2010-11)
Genotypes	LB 1 (CIP391004.18)	12.9 g	-	-
	LB 2 (CIP391046.14)	10.2 h	-	-
	LB 3 (CIP391058.175)	19.1 e	32.55 bc	38.91 c
	LB 4 (CIP393077.159)	23.7 c	34.06 b	-
	LB 5 (CIP393085.5)	24.7 b	-	-
	LB 6 (CIP393280.64)	22.9 c	27.78 d	41.16 b
	LB 7 (CIP393371.58)	27.00 a	38.59 a	50.78 a
	LB 8 (CIP395011.2)	26.90 a	34.36 b	-
	LB 9 (CIP396004.337)	15.3 f	-	-
	LB 11 (CIP396031.108)	19.8 de	-	-
	LB 12 (CIP396031.119)	19.1 e	33.56 b	-
	LB 14 (CIP396244.12)	21 d	30.57 c	-
	Diamant	10.5 h	31.55 c	36.28 d
Environment	Jamalpur	21.55 a	43.57 a	40.48 c
	Bogura	12.36 b	25.02 c	41.87 b
	Munshiganj	21.96 a	30.04 b	43.52 a
	Rangpur	-	-	41.25 b
	Joydebpur	-	-	-
	Jashore	-	-	-
Level of Significance	Genotypes (G)	**	**	**
	Environment (E)	**	**	**
	$G \times E$	**	**	**
CV (%)		8.59	5.27	5.27

**Significant at 0.01 level of probability

31.55 t/ha. The second highest yielder was LB-8 (34.36 t/ha), followed by LB-4 (34.06 t/ha), LB-12 (33.56 t/ha) and LB-3 (32.55 t/ha). There was no late blight infection in any field during SYT due to unfavorable environmental conditions for disease development in 2009-10.

Considering tuber shape, size, color and yield, three clones (LB-3, LB-6 and LB-7) were selected for AYT. The AYT consisted of three clones and Diamant at four trial sites (Rangpur, Bogura, Jamalpur, and Munshiganj) (Table 2). Results revealed significant variation in tuber yield at all

locations. The outstanding performance was obtained in the clones LB-6 (41.16 t/ha) and LB-7 (50.78 t/ha) whereas the check variety Diamant produced 36.28 t/ha. Among the trial sites, mean tuber yield across the test clones varied from 40.48 to 43.52 t/ha. From mean AUDPC, disease in AYT was the highest in check Diamant followed by LB-3. Considering AUDPC, only LB-6 and LB-7 showed high and consistent resistance to Late Blight (Table 3).

Two clones - LB-6 and LB-7 were selected for evaluation in RYT at six locations, (Joydebpur, Jashore, Rangpur,

Table 3. Average AUDPC for Late Blight of advanced CIP clones and check varieties in PYT, AYT and RYT at different experimental sites in Bangladesh

Factor	Genotype	AUDPC			
		PYT (2008-09)	SYT (2009-10)	AYT (2010-11)	RYT (2011-12)
Genotypes	LB 1 (CIP391004.18)	1983	-	-	-
	LB 2 (CIP391046.14)	2172	-	-	-
	LB 3 (CIP391058.175)	952	-	212	-
	LB 4 (CIP393077.159)	743	-	-	-
	LB 5 (CIP393085.5)	614	-	-	-
	LB 6 (CIP393280.64)	587	-	251	69
	LB 7 (CIP393371.58)	486	-	68	40
	LB 8 (CIP395011.2)	686	-	-	-
	LB 9 (CIP396004.337)	1982	-	-	-
	LB 11 (CIP396031.108)	631	-	-	-
	LB 12 (CIP396031.119)	1775	-	-	-
	LB 14 (CIP396244.12)	992	-	-	-
	Diamant	2214	-	716	939
Environment	Jamalpur	1917	-	153	475
	Bogura	1357	-	519	782
	Munshiganj	376	-	47	1
	Rangpur	-	-	526	839
	Joydebpur	-	-	-	1
	Jashore	-	-	-	1
Level of Significance	Genotypes (G)	**	-	**	**
	Environment (E)	**	-	**	**
	G × E	**	-	**	**
CV (%)		22.6		22.5	37.5

**Significant at 0.01 level of probability

Bogura, Jamalpur and Munshiganj) along with two standard varieties as required for recommendation for release as commercial varieties (Table 4, 5). Plants of all tested clones including LB-6 and LB-7 were taller compared to their corresponding check varieties Cardinal and Diamant. At the same time, LB-6 and LB-7 produced more vigorous plants than these check varieties (Table 4). The plant vigor score suggested that LB-6 and LB-7 have the capability to grow faster in all agro-ecologies of Bangladesh.

Late blight resistance of LB-6 and LB-7 was further verified in the 6 locations of RYT, whereas the check variety, Diamant was highly susceptible to Late Blight (Table 6). The susceptible entries showed early senescence as late blight progressed in all

but SYT reduced vigor and ground cover. The resistant clones showed more vigorous plants with later senescence and overall late foliage maturity, as often associated with resistant varieties. The disease also caused a significant reduction in tuber formation in the susceptible genotypes, such that resistant clones/varieties produce more tubers (Table 4).

Tables 5 and 6 show the location-wise average yields of the clones at 65 and 90 DAP, indicating the earliness and performance at full maturity. The clone LB-7 produced the highest yield at 65 DAP followed by the check Diamant, while the clone LB 6 produced the lowest, indicating that the former clone can be used as an early variety, but the latter, LB-6 requires a

Table 4. Mean vegetative and tuber characteristics of the varieties in RYT

Variety	Plant height (cm)	% Foliage coverage	Plant vigor (1-5) at 60 DAP	No. of stems /plant	No. of Tuber/ plant	Senescence at 75 DAP (1-5 Scale)
LB-6	87.5	91.38	4.20	3.58	8.96	1.25
LB-7	83.6	95.76	4.51	4.45	10.46	1.75
Diamant	63.7	71.25	3.37	4.92	8.85	4.33
Significance level	**	**	**	**	**	**

**Significant at 0.01 level of probability; NS=Not Significant; Plant vigor (1=low vigor and 5= very high vigor); Senescence 1-5 scale, 5=0-20%; 4=21-40%; 3= 41-60%; 2= 61-80% and 1= 81-100% senescence.

Table 5. Mean tuber yield of the 2 CIP LB resistant clones at 65 DAP at six trial sites in RYT

Location	Yield at 65 Day (t/ha)			Average Yield (t/ha)
	LB-6	LB-7	Check (Diamant)	
Joydebpur	5.07	10.87	11.33	9.09
Bogura	9.06	29.77	12.58	17.14
Munshigonj	1.66	9.15	10.25	7.02
Jashore	5.90	20.06	14.80	13.59
Jamalpur	17.69	26.01	20.17	21.29
Burirhat	13.34	23.13	18.58	18.35
Mean	8.79	19.83	14.62	-
Level of significance	Genotypes (G) ** Environment (E)** G × E**			
CV (%)	5.47			

Table 6. Mean tuber yield of the 2 CIP LB resistant clones at 90 DAP at six trial sites in RYT

Location	Yield at 90 Day (t/ha)			Average Yield (t/ha)
	LB-6	LB-7	Check (Diamant)	
Joydebpur	19.18	22.34	22.73	21.42
Bogura	27.33	38.79	14.03	26.72
Munshigonj	46.21	53.26	32.90	44.12
Jashore	35.79	49.02	30.11	38.31
Jamalpur	36.38	48.48	35.64	40.17
Rangpur	28.28	41.89	21.81	30.66
Mean	32.20	42.30	26.20	-
Level of significance	Genotypes (G) ** Environment (E)** G × E**			
CV (%)	5.20			

mid-length growing season (90 days). The highest yield was consistently observed for LB-7, which continued to stand out in RYT where it averaged 42.30 t/ha and reached 53.26 t/ha at Munshiganj (Table 6). LB 6 averaged 32.20 t/ha in the RYT. The latter clone received additional merit for its red skin color.

The check variety Diamant produced 26.20 tons, respectively on average at the best. LB-6 produced 22.90% higher yield and LB-7 produced 61.41% higher yield, respectively than Diamant in the RYT (Table 6).

Tuber yields in the on-farm trials in the 3 locations ranged from 25.55 to 39.75 t/ha. The average highest yield was found in LB-7 (35.69 t/ha) which produced 44.08% higher yield compared to the check variety Diamant (24.77 t/ha) (Table 8). LB-6 was the 2nd highest average yielder (32.04 t/ha) and produced 29.35% higher yield compared to Diamant (24.77 t/ha) (Table 8).

Tuber dry matter and Keeping Quality

The tuber dry matter and the keeping of potato tubers are important criteria in selecting and recommending new varieties in Bangladesh. Tuber dry matter contents of LB-6 and LB-7 were 20.42% and 19.00%, respectively, while that of Diamant was 19.88%. In the recent studies (Table 7) CIP clone LB-6 had post-harvest qualities comparable to the checks. Weight loss in CIP clones, LB-6 and LB-7 after 90 days of storage was 16.25 and 32.95% as compared to check variety Diamant, 15.25%. Similarly, rottage

loss was 14.07 and 29.92% as compared to 7.22 % in checks.

Responses to other diseases

LB-6 and LB-7 each presented less than 10% of plants with symptoms of PLRV or PVY in the RYT trials (Fig. 3). Significant incidence of PVY (nearly 50% in Diamant) indicated that pressure was high enough to cause infection. Thus, although not reported by CIP to carry extreme resistance to PVY (Table 1), these clones may carry partial resistance. Scarce incidence of PLRV was observed (less than 10%) in the test clones or the control. LB-6 is reported to be PLRV resistant, while LB-7 is not. It is likely that symptoms would be found in the latter clone if observations were made during the growth of plants from tubers of plants exposed to the virus and its vectors in a previous season (secondary infection).

Varietal description

Two clones that consistently performed well for yield and disease resistance – LB-6 and LB-7 - were recommended for variety release. The morphological characteristics (Fig

Table 7. Tuber dry matter (%) and post-harvest storage behaviour of the candidate potato varieties

Variety	Tuber dry matter at harvest (90 DAP)	Ambient condition (After 90 days of storage)	
		% Weight loss	% Rottage loss
LB-6	20.42±1	16.25	14.07
LB-7	19.00±1	32.95	29.92
Diamant (Check)	19.88±1	15.25	7.22

Table 8. On-Farm Trial of LB-resistant potato clones in three locations at 90 DAP

Variety	Yield (t/ha)			Mean yield (t/ha)	% Yield increase over control
	Bogura	Jamalpur	Comilla		
LB-6 (393280.64)	25.55	31.00	39.58	32.04	29.35%
LB-7 (393371.58)	37.78	30.13	39.17	35.69	44.08%
Diamant (Check)	10.00	28.49	35.83	24.77	-

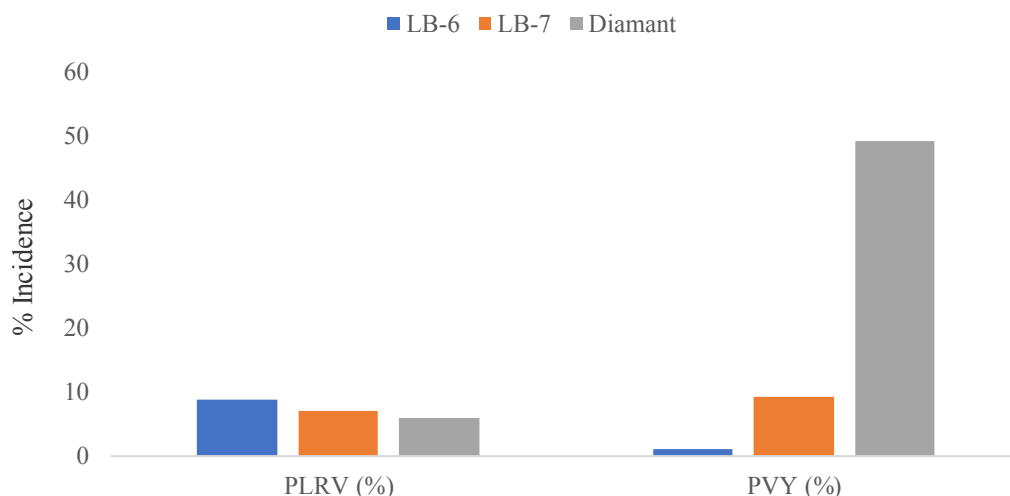


Fig. 3 Virus disease incidence of PLRV and PVY in potato varieties in RYT

Plate 1 & 2) of the two clones (BARI Alu-46 and BARI Alu-53) were assessed by DUS (Distinct, uniform and stable) criteria set out by the National Seed Board of Bangladesh.

BARI Alu-46

LB-7 (CIP 393371.58) was released in 2013 as Bangladesh's first late blight-resistant potato variety with the name BARI Alu-46 (Figs. 4-5).

BARI Alu-53

LB-6 (CIP 393280.64) was released in 2014 as Bangladesh's second late blight-resistant variety and named BARI Alu-53 (Figs. 6-7).

Morphological characteristics of BARI Alu-46 (LB-7, CIP 393371.58) Courtesy International Potato Center (Fig. 5).

Plant parts	Characteristics
Plant habit	Medium-sized plant, semi-erect, strong stem, predominantly green.
Foliage and flowering	Small to medium size shiny green leaves, white flower color and regular flowering habit.
Tubers	Cream white tubers have an oblong shape, superficial eyes, medium to large tuber sizes, intermediate tuber number per plant, and cream flesh.
Sprouts	Red-purple, cylindrical, pubescence at sprout base weak.

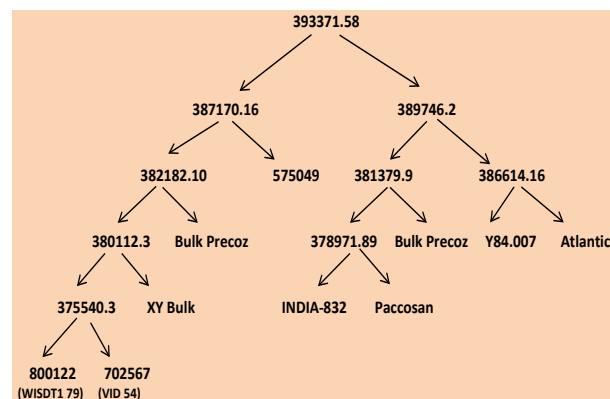


Fig. 4 Parentage, crossing out lines of BARI Alu-46 (LB-7, CIP 393371.58) Courtesy International Potato Center

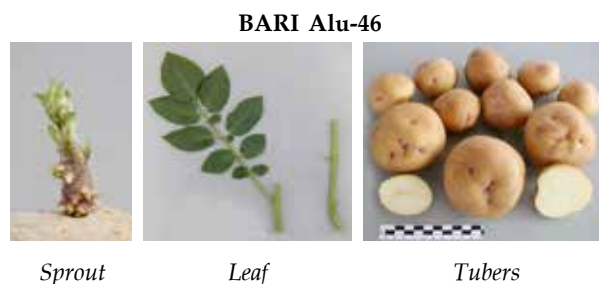


Fig. 5 Morphological characteristics of BARI Alu-46 (LB-7, CIP 393371.58)

Adaptive trials and farmer's assessment

The average yield of BARI Potato-46 and BARI Potato-53 were 29.87 and 26.81 t/ha, respectively. The tuber yield of BARI Potato-46

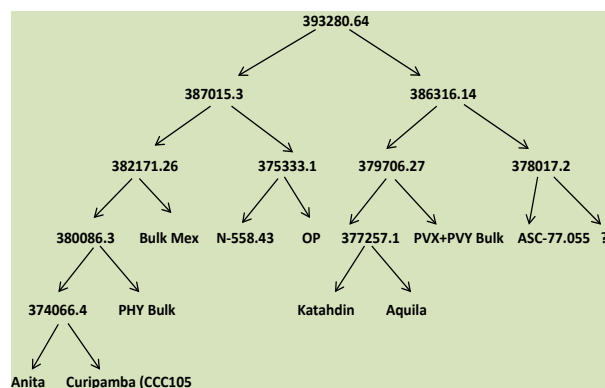


Fig. 6 Parentage, crossing out lines of BARI Alu-53 (LB-6, CIP 393280.64) Courtesy International Potato Center

ranged from 15.30-37.14 t/ha, where the highest tuber yield was recorded in Thakurgaon and the lowest was in Gazipur (Table 9). The tuber yield of BARI Potato-53 ranged from 23.98-34.05 t/ha, where the highest tuber yield was recorded in Thakurgaon and the lowest was in Panchagarh (Table 10).

DISCUSSION

Potato varieties with resistance to Late Blight could be used to contest the disease.

Morphological characteristics of BARI Alu-53 (LB-6, CIP 393280.64) Courtesy International Potato Center (Fig. 7).

Plant parts	Characteristics
Plant habit	Medium-size plant, semi-erect, strong stems.
Foliage and flowering	Small to medium size leaves purple flower color and regular flowering habit.
Tubers	Oblong shape, red skin color, superficial eyes, medium to large tuber sizes, high tuber number per plant, pale yellow flesh
Sprouts	Purple

BARI Alu-53

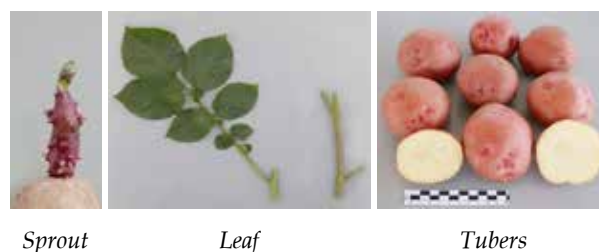


Fig. 7 Morphological characteristics of BARI Alu-53 (LB-6, CIP 393280.64)

Table 9. Yield and farmer's assessment of BARI Alu-46 at farmer's fields in 12 locations (188 trials) at 90 DAP under Adaptive trials, 2015-16

Location	No. of trial	Yield (t/ha)	Farmers preference		
			Late Blight resistance	Plant vigor	Acceptability (Skin color, yield and market access)
Thakurgaon	23	37.14	2.50	3.00	2.00
Dinajpur	10	18.25	2.50	3.00	1.00
Rangpur	50	29.39	3.00	3.00	1.00
Bogura	22	34.09	3.00	3.00	1.00
Rajshahi	20	28.71	2.50	3.00	2.50
Jashore	10	30.70	3.00	3.00	1.50
Gazipur	5	15.30	3.00	2.50	1.00
Munshiganj	9	32.02	3.00	2.00	1.00
Comilla	19	32.12	3.00	2.00	1.00
Jamalpur	10	34.06	3.00	2.50	1.50
Sherpur	10	33.15	3.00	2.00	2.00
Total location (12)	188	29.87 ± 6.62	2.86	2.64	1.41

Late Blight Resistance Scale 1-3, 3: Excellent, 2: Medium and 1: Susceptible; Plant vigor Scale 1-3, 3: Highly vigorous; 2: Medium vigor; 1: Average vigor; Acceptability scale 1-3: 3: High; 2: Medium; 1: Low

Table 10. Yield and farmer's preference of BARI Alu-53 in 62 adaptive trials in farmer's fields in 12 locations at 90 DAP, 2015-16

Location	No. of trial	Yield (t/ha)	Farmers preference		
			Late Blight resistance	Plant vigor	Acceptability (Skin color, yield and market access)
Thakurgaon	7	34.05	2.0	2.0	2.5
Rangpur	10	27.59	2.5	2.5	2.0
Bogura	28	28.79	2.5	3.0	2.5
Jashore	10	28.22	3.0	2.0	3.0
Panchagarh	7	23.98	2.5	2.5	3.0
Total location (6)	62	26.81± 5.30	1.9	1.4	1.6

Late Blight Resistance Scale 1-3, 3: Excellent, 2: Medium and 1: Susceptible; Plant vigor Scale 1-3, 3: Highly vigorous; 2: Medium vigor; 1: Average vigor; Acceptability scale 1-3: 3: High; 2: Medium; 1: Low

The use of race-specific resistance has turned out not to be stable because *P. infestans* is able to overcome this type of resistance. Race non-specific resistance is expected to be more stable but, unfortunately, this type of resistance to *P. infestans* is associated with late foliage maturity (Johnson, 1979). In our study, CIP bred LB resistant clones showed late foliar maturity with more vigorous plants and delayed senescence as compared to the control varieties (Table 6). Nevertheless, our data on yield at 90 DAP enables their classification as medium maturing, and not late in terms of tuber set and bulking. Additionally, BARI Alu-46 yielded well at 65 DAP, qualifying it as early. The implications of the vigorous plant habit on harvesting and storage of tubers may need further research in order to minimize weight loss and rottage, but it is not seen as detrimental to the acceptance of new varieties in Bangladesh.

The presence of an aggressive, variable population of the pathogen may interfere with the stability of partial resistance (Latin *et al.*, 1981) and a move towards the greater aggressive populations of *P. infestans* will result in the overall reduction in the resistance of potato cultivars. In addition, differential changes in the ranking of partially resistant cultivars after exposure to different genotypes

of the pathogen may arise (Leonard and Moll, 1979). Since both partial and race-specific resistance can fall apart following the appearance and spread of more aggressive pathogen strains, using isolates from the most aggressive populations is helpful in evaluating resistance. In practice, testing the accessions across locations with diverse pathogen populations may easily achieve this.

Hossain *et al.* (2018) studied late blight resistance in detached leaves of nine potato varieties and found that LB-6 and LB-7 possessed much better resistance compared to the checks and other varieties. Saha *et al.* (2018) evaluated 35 potato varieties in field plots for three years (2015-16, 2016-17 and 2017-18), and found that the variety BARI Alu-46 (LB-7), imported varieties Alouette and Carolus were highly resistant; BARI Alu-53 (LB-6) and BARI Alu-77 were moderately resistant, and a few were partially resistant to late blight. Rahman *et al.* (2018) also found similar results for these two varieties. Consistent performance including low AUDPC and sparse sporulation on slight lesions over multiple years and plot locations in several environments suggest that BARI Alu-53 and BARI Alu-46 may carry a durable type of resistance to late blight. However, this does not discount the need

for continued vigilance including occasional fungicide applications where late blight is seen, as this may help limit changes in the pathogen population.

Efforts to control virus diseases during evaluation included chemical control of aphids and the use of healthy tuber seeds from TCRC research stations to plant each trial. Thus, the incidence of PLRV was low, as observed in RYT. LB-6 and LB-7 showed lower incidences of PVY than did Diamant, although neither carried extreme resistance according to the CIP catalog of advanced potato clones. Table 1 indicates that a number of the test clones carry extreme resistance to PVX and/or PVY, and resistance to infection or tolerance to PLRV, but not all of these performed well enough for variety release in Bangladesh. Notably, those that did are both PVX resistant and LB-6 is resistant or tolerant to PLRV. The use of varieties resistant to PVX, PLRV, and PVY can reduce net losses from potato production due to reduced yield, tuber defects, and downgrading of seed crops (Solomon-Blackburn and Barker, 2001). Bangladesh's current variety trials include CIP-bred clones with multiple virus resistance, the release of which may contribute to increasing the country's seed production capacity with positive economic and environmental consequences.

CONCLUSION

From the results on farmers' fields and those on-stations, it can be concluded that LB-6 and LB-7 possess good resistance to the devastating disease late blight and produce equivalent or higher yields than predominant commercial varieties in diverse agro-ecological regions of Bangladesh. Accordingly, the National Seed Board of Bangladesh released LB-7 as BARI Alu-46 and LB-6 as BARI Alu-53 in 2014 and 2015, respectively. But Breeders as well

as Pathologists, suggest that especially for varieties with late foliage maturity, there should be one or two fungicide sprays when conditions are conducive to Late Blight so that the pathogen cannot complete many life cycles and will be less likely to overcome the resistance of the varieties. These are the first Late Blight resistant varieties of Bangladesh, identified through testing and selection from CIP bred materials. Continued stable performance has been observed across extensive adaptive trials in recent years. TCRC is currently producing quality seed of these two Late Blight Resistant Potato varieties to distribute among growers, along with promotional activities and monitoring of end-users perceptions and possible implications on system productivity, crop, and disease management.

Population development and stability analysis in tropical and subtropical environments of Peru identified promising and well-adapted candidate varieties for Bangladesh. Nevertheless, the >25 years from crossing to the releases reported here call for more dynamic germplasm exchange and assessment so that national programs may avail the latest advances inbreeding in shorter time frames. Prior to its release in Bangladesh as *BARI Alu-46*, CIP 3933371.58 was released in Peru (2007) as Chugmarina, in Kenya as Kenya MPYA, and in Ethiopia as Belete. CIP 393371.58 And CIP393280.64 have proven to be excellent female and male parents, respectively, in CIP's efforts to expand the adaptation of its B3 population with high levels of late blight resistance to warmer climates of mid-elevation tropic and sub-tropical environments (Gastelo *et al.*, 2014). They have also produced high-performing progeny in TCRC's crossing program aimed at developing mid- and short-duration varieties with multiple diseases and stress resistances.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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