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Genetic progress for tuber yield and related traits of potato (*Solanum tuberosum* L.) in Ethiopia

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Little work has been done to evaluate the progress made in potato improvement in Ethiopia during the past three decades and information about traits most contributing to progress in yield is scarce. Hence, this experiment was conducted to estimate rate of genetic improvement made over time in yield and to determine traits most contributing to progress in tuber yield. Twenty varieties of potato released in Ethiopia between 1987 and 2013 and one farmers` cultivar were evaluated at Holetta and Adaberga, central highlands of Ethiopia in 2017 main cropping season. The experiment was arranged in a randomized complete block design with three replications. Analysis of variance for tuber yield and tuber related traits showed the existence of highly significant (P < 0.01) differences between varieties for all traits. There was a total tuber yield increment of 137.39 and 0.851% over farmers` cultivar and the oldest variety, respectively. The relative rate of gain was 1.15 and 1.42% year^{-1} for total tuber yield and marketable tuber yield, respectively. The annual rate of genetic progress was found to be 0.3177 and 0.3401 ton year^{-1} for total tuber yield and marketable tuber yield, respectively.

Key words: Genetic progress, tuber yield, yields related traits, *Solanum tuberosum* L., regression.

INTRODUCTION

Potato (*Solanum tuberosum* L.*)* is one of the vital tuber crops in terms of food security for a growing population and increased hunger rates (CIP, 2018). Since its introduction to Ethiopia by a German immigrant in 1858 Wilhelm Schimper, the crop was cultivated by few number of farmers as a garden crop. The expansion and its adoption by Ethiopian farmers were gradual and stagnant for several decades (Baye and Gebremedhin, 2013). Strategic potato research in Ethiopia began in 1975 with the understanding of the constraints challenging

its production and productivity (Baye and Gebremedhin, 2013). The development and dissemination of more than 36 improved varieties, coupled with other technological packages, contributed greatly to the improvement and rapid expansion in potato production (MANR, 2016). The major objective of potato breeding has been to develop potato cultivars that have maximum yield potential, adaptable to wide agro-ecologies and resistant to late blight that has been the most devastating disease throughout the dominant potato producing highlands of

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Table 1. Description of the study sites.

Location	Latitude	Longitude	Altitude (m.a.s.l.)	Mean annual rain fall (mm)	Mean annual temperature (°C)
Holetta Research Centre	09° 00' N	38° 29' E	2400	1100	14.15
Adaberga Research station	09° 16' N	38° 23' E	2500	1225	18.0

Source: HARC (2015).

the country (Wassu, 2016). However, considerable number of released varieties became vulnerable to potato devastating disease because of the pathogen (*Phytophthora infestans)* ability to rapidly overcome resistant genes even though improvements on late blight resistance were made by breeders (Getachew et al., 2016; Wassu, 2017). This indicates the study on genetic progress with identifying the most important traits for yield as well as resistance of the crop for late blight was the missing component except little attempt made by Haramaya University (Wassu, 2017). Hence periodic assessment of genetic progress for these important traits could supplement the breeding program of the crop in the country. Furthermore, estimation of genetic progress of a breeding program and periodic assessment of advance (Wassu, 2017; CGIAR, 2016) in the genetic gain of a crop is vital to understand changes produced by breeding, to assess the past efforts made in genetic yield potential and to put forward future breeding strategy.

MATERIALS AND METHODS

The field trial was carried out under rain fed condition at two locations, Holetta Agricultural Research Center and Adea Berga Research station (Table 1) during the main cropping season of 2017 using 20 released varieties and 1 farmers` cultivar of potato (Table 2). The experiment was arranged in a randomized complete block design with three replications. The experimental plot size was 4 rows each 3 m long and 3.6 m wide; plant spacing was 30 cm between plants and 75 cm between rows. Fertilizer used in the rate of 108.44 kg N, 92.43 kg P and 16.59 kg S per hectare in the form of Urea (143 kg/ha) and blended fertilizer (NPS) (237 kg/ha) as per the recommendation for the study area (MALR, 2017). Other agronomic practices and data collection was conducted based on the recommendations of Holetta Research Centre (Lemaga et al., 1992).

Data analysis

All data were subjected to separate analysis of variance (ANOVA) of individual locations and a combined ANOVA over locations was done using the procedure of SAS software version 9.3 (SAS Institute, 2010) and a general linear model (GLM) for tuber yield related traits (Gomez and Gomez, 1984). The combined analysis of variance over locations were computed after homogeneity test of error variances using F-test as stated by Gomez and Gomez (1984).
Regression analysis was performed to calculate the genetic gain of yield and other yield related traits. The average annual rate of genetic gain for each trait was estimated by regressing of the mean value of each trait against the corresponding year of release of

each variety (Singh and Chaudhary, 2007).
The regression equation was, Y = a + bx, assuming the linear relationship where Y = the mean value of the dependent variable, x = the mean value of the independent variable, a = the constant value and b = the regression coefficient.

$$\text{Annual rate of gain } (b) = \frac{CovXY}{VarX}$$

Where, X = the year of variety release, Y = the mean value of each character for each variety, Cov = Covariance and Var = Variance.
Regression analysis was conducted taking tuber yield and other traits dependent and year of release as independent variable. The annual rate of genetic gain achieved over the last 30 years of potato improvement was determined as the ratio of genetic gain to the corresponding mean value of the oldest variety and expressed as percentage.

Relative annual rate of gain = Cov (X, Y)/Var (X)

Where, X is the year of variety release, Y is the mean value of each trait for each variety; Cov (X,Y) is the covariance of X and Y, and Var (X) is variance of X (year of variety release). Percent genetic gain per year for each variety was calculated as:

Percent Genetic Gain Year^{-1} = [(XG-XAL-624)/XAL-624]/YG-YAL-624 × 100

Where, X is the mean value of observations for a given trait, Y is the year of release of each variety (G), AL-624 is the oldest variety of potato released in 1987.
The increment over farmers' cultivars for each trait was calculated as:

Percent increment of Variety (%) = XG - XFC/XFC × 100

Where, XG is the mean value of each variety for each trait, XFC is the mean value of the farmers' cultivar (Nech Abeba) in Central highlands of Ethiopia.
In this experiment, Alemaya 624 was considered as the oldest variety since it was the first potato variety released in the country in 1987.
Step-wise regression analysis was computed using the SAS software (version 9.3) (SAS Institute, 2010) to identify the most contributing traits to the variability that exists in the yield related traits were computed (Gomez and Gomez, 1984).

RESULTS

Improvement made on tuber yield and yield related traits

Yield data of each mean values from combined analysis

Table 2. List of experimental materials included in the study.

No.	Variety	Accession code	Year of release	Breeding centre	Recommended altitude (m.a.s.l)
1	Dagim	CIP-396004.337	2013	ADARC	2000-2800
2	Bubu	CIP-384321.3	2011	HU	1700-2000
3	Belete	CIP-393371.58	2009	HARC	1600-2800
4	Gudene	CIP-386423.13	2006	HARC	1600-2800
5	Challa	CIP 387412-2	2005	HU	1700-2000
6	Mara chare	CIP 389701-3	2005	AwARC	1700-2700
7	Shenkolla	KP- 90134.5	2005	AwARC	1700-2700
8	Gabissa	CIP 3870-96-11	2005	HU	1700-2000
9	Gera	KP-90134.2	2003	ShARC	2700-3200
10	Jalene	CIP-384321.19	2002	HARC	1600-2800
11	Gorebella	CIP-382173.12	2002	ShARC	1700-2400
12	Guassa	CIP-384321.9	2002	ADARC	2000-2800
13	Zengena	CIP-380479.6	2001	AwARC	2000-2800
14	Zemen	AL-105	2001	HU	1700-2000
15	Bedassa	AL-114	2001	HU	2400-3350
16	Chiro	AL-111	1998	HU	2700-3200
17	Wechecha	KROEZE 72-2951	1997	HARC	1700-2800
18	Menagesha	CIP-374080.5	1993	HARC	Above 2400
19	Awash	CIP-378501.3	1991	HARC	1500-2000
20	Alemaya 624	AL-624	1987	HU	1700-2400
21	Nech Abeba		...	...	Central highlands

*HU = Haramaya University, HARC = Holetta Agricultural Research Centre, AwARC = Awassa Agricultural Research Centre, ShARC = Sheno Agricultural Research Centre, ADARC = Adet Agricultural Research Centre.
Source: MANR (2016)

of variance were used to regress the breeding progress of varieties for their tuber yield and other important traits. Potato varieties had huge total and marketable tuber yield difference. Trends in genetic progress, percent genetic gain over location and annual relative rate of genetic progress were calculated and presented in Tables 3 to 5.

Total tuber yield of variety Belete showed an increment of 137.39 and 0.851% over Nech Abeba (farmers` cultivar) and the oldest variety (AL-624), respectively (Table 5). The trend also showed total tuber yield increment over the oldest variety was 1.08% (Awash), 0.79% (Gudene and Gabissa) and 0.78% (Bedassa). On the other hand, the recent variety Dagim had a yield progress of -0.596% over the oldest variety. Hence, the yield increment was not constant throughout the breeding period and some varieties had yield performance below the oldest variety AL-624.

In terms of potato tuber yield, the genetic progress made over the last two to three decades since the first improved potato variety AL-624 was released comparing with the maximum yielding variety Belete was 0.009 t ha^{-1}. The relative annual rate of gain was 1.15 and 1.42% year^{-1} for total tuber yield and marketable tuber yield, respectively. Both the average tuber number and tuber

weight showed annual relative gain of 0.01 and 0.79% year^{-1}. Similarly, the annual rate of genetic progress in the present study was found to be 0.3177 ton year^{-1} (20.27%) and 0.3401 ton year^{-1} (24.55%) per hectare for total and marketable tuber yield, respectively (Figure 1a). On the other hand, non-significant and positive regression value was recorded for average tuber number and average tuber weight against year of variety release (Table 4).

Improvements on tuber quality traits

Year of variety release had positive and significant regression value with tuber dry matter content, starch content and total starch yield, but positive and statically non-significant positive value for tuber specific gravity (Table 4) indicating that potato breeders made improvements on tuber quality traits through breeding for the last two to three decades. Among quality traits studied, total starch yield had maximum relative gain 1.70% year^{-1} followed by starch and dry matter content (0.80 and 0.44% year^{-1}, respectively). For both tuber dry matter and starch content in percent, the annual rate of genetic progress in the present study was found to be

Table 3. Estimates of the mean annual relative genetic gains and correlation coefficients of all traits with total tuber yield r (TTY).

Trait	Over all mean	Annual RGG (% year^{-1})	Correlation coefficients r (TTY)
Days to 50% flowering(days)	59.63	-0.04	0.066
Days to physiological maturity (days)	99.14	0.38	-0.077
Number of leaves per hill	40.79	0.33	0.387
Plant height (cm)	59.36	0.46	0.657**
Stem number per plant	4.43	0.71	0.531*
Average tuber number per hill	11.26	0.01	0.599**
Average tuber weight (gtuber^{-1})	51.55	0.79	0.475*
Total tuber yield (t ha^{-1})	25.26	1.15	-
Marketable tuber yield (t ha^{-1})	21.39	1.42	0.985**
Unmarketable tuber yield (t ha^{-1})	3.87	-0.53	0.268
Specific gravity (g cm^{-3})	1.09	0.04	0.445*
Dry matter content (%)	21.89	0.44	0.541*
Starch content (g/100 g^{-1})	14.26	0.80	0.537*
Total starch yield (t ha^{-1})	3.60	1.70	0.937**

RGG = Rate of genetic gain, r (TTY) = correlation coefficient for total tuber yield

Table 4. Estimates of mean values, coefficient of determination (R^2), regression coefficient (b), intercept and correlation coefficient with year of release (ryor) of various yield and yield related traits from linear regression of the mean values of each traits for the variety.

Trait	Mean	R^2	b	Intercept	ryor
Days to 50% flowering(days)	59.63	0.0038	-0.0222	104.60	-0.061
Days to physiological maturity (days)	99.14	0.3384	0.3507	-602.56	0.582**
Leaf number per hill	40.79	0.0477	0.1544	-268.20	0.219
Plant height (cm)	59.36	0.0558	0.2900	-520.84	0.241
Stem number per plant	4.43	0.0492	0.0320	-59.21	0.222
Average tuber number per hill	11.26	0.0001	0.0008	9.62	0.003
Average tuber weight (gtuber^{-1})	51.55	0.1260	0.4160	-779.99	0.355
Total tuber yield (t ha^{-1})	25.26	0.2027	0.3177	-610.25	0.450*
Marketable tuber yield (t ha^{-1})	21.39	0.2455	0.3401	-659.03	0.496*
Unmarketable tuber yield (t ha^{-1})	3.87	0.0257	-0.0195	42.97	-0.160
Specific gravity (g cm^{-3})	1.09	0.1690	0.0004	0.21	0.411
Dry matter content (%)	21.89	0.2054	0.0981	-174.40	0.453*
Starch content (%)	14.26	0.1950	0.1168	-219.45	0.442*
Total starch yield (t ha^{-1})	3.60	0.2474	0.0677	-131.87	0.497*

ryor= correlation coefficient with year of release.

0.1326 (R^2=0.2063) and 0.1633 (R^2=0.2077), respectively (Figure 1b and c). Total starch yield also showed positive significant value with year of variety release, whereas tuber specific gravity had positive and statistically non-significant regression value against year of variety release (Table 4).

Genetic progress on growth and Phenological traits

Year of variety release had positive and significant regression value with days to physiological maturity. Non-significant negative regression value was recorded for days to 50% flowering indicating the breeding made some weak improvements for this trait. Days to physiological maturity showed a significant positive regression value with a certain amount of increase against the year of variety release without affecting yield of potato (Table 4). However, days to 50% flowering had negative and statistically non-significant correlation value with yield of potato varieties indicating that high yielding varieties have a retarded flowering. On the other hand, all

Table 5. Trends in genetic progresses in total tuber yield of potato released from 1987 to 2013.

| Variety | Year of release | Mean TTY (t ha^{-1}) | Yield increment over | | | |
| | | | Nech Abeba | | AL-624 | |
			t ha^{-1}	%	t ha^{-1}	%
Nech Abeba	Pre-1975	13.8	--	--	---	---
Alemaya-624	1987	27.7	1.00	99.96	--	--
Awash	1991	28.9	1.09	108.59	0.011	1.079
Menagesha	1993	16.1	0.16	16.01	-0.070	-6.997
Wechecha	1997	17.2	0.24	24.07	-0.038	-3.795
Chiro	1998	28.1	1.03	102.70	0.001	0.125
Bedassa	2001	30.7	0.74	74.39	-0.009	-0.913
Zemen	2001	25.8	1.22	121.72	0.008	0.778
Zengena	2001	15.9	0.86	86.44	-0.005	-0.483
Mean	2001	24.13	0.15	15.02	-0.030	-3.034
Guassa	2002	17.8	0.74	73.57	-0.009	-0.880
Gorebella	2002	30.4	0.28	28.44	-0.024	-2.384
Jalene	2002	23.8	1.20	120.00	0.007	0.668
Mean	2002	24.11	0.72	72.26	-0.009	-0.924
Gera	2003	29.6	1.14	113.61	0.004	0.427
Gabissa	2005	31.6	0.95	94.96	-0.001	-0.139
Shenkolla	2005	29.6	1.28	128.29	0.008	0.787
Marachere	2005	20.4	1.14	113.69	0.004	0.382
Challa	2005	26.3	0.48	47.68	-0.015	-1.452
Mean	2005	27.5	0.90	90.18	-0.003	-0.272
Gudene	2006	31.8	1.30	130.09	0.008	0.793
Belete	2009	32.8	1.37	137.39	0.009	0.850
Bubu	2011	28.9	1.09	109.09	0.002	0.190
Dagim	2013	23.4	0.69	68.97	-0.006	-0.596

*TTY = total tuber yield (t ha^{-1}), t ha^{-1} = ton per hectare, AL_624 = Alemaya 624.

the phenological and growth traits except days to physiological maturity demonstrated statically non-significant values with the year of variety release (Table 4). Days to 50% flowering and days to physiological maturity showed annual relative gains of -0.04 and 0.38% year^{-1}. The other growth traits like number of leaves per hill, plant height and stem number per hill showed relative gains of 0.33, 0.46, and 0.71% year^{-1}, respectively. The genetic progress for growth traits recorded was 0.29 cm for plant height, 0.15 for number of leaves per plant and 0.03 for stem number per hill.

The results of stepwise regression analysis between total tuber yield and other traits were presented in Table 6. The traits (predictors) that were retained in the model after regression analysis with the dependent traits were significant (P ≤ 0.05 and P ≤ 0.01) and regarded as the most important traits for predicting the tuber yield. Based on stepwise regression analysis, the best combination of characters that contributed to genetic progresses in tuber yield included were average tuber number per hill, stem number per hill and marketable tuber yield. About 98.2% of the variations on total tuber yield were explained by

stem number per hill followed by average tuber number per hill and marketable tuber yield t ha^{-1} contributing to 97.8 and 97.2%, respectively. Therefore, it can be considered that changes in the above three traits had possibly contribution to the changes in total tuber yield in the last two to three decades of potato breeding in Ethiopia.

DISCUSSION

Improvements made on tuber yield and other yield related traits

Strategic potato research in Ethiopia began in 1975 amid to solve the constraints challenging the production and productivity of potato (Baye and Gebremedhin, 2013). The development and dissemination of many improved varieties, coupled with other technological alternative, contributed greatly to the improvement and rapid expansion in potato production. More than 36 improved potato varieties have been recommended from different
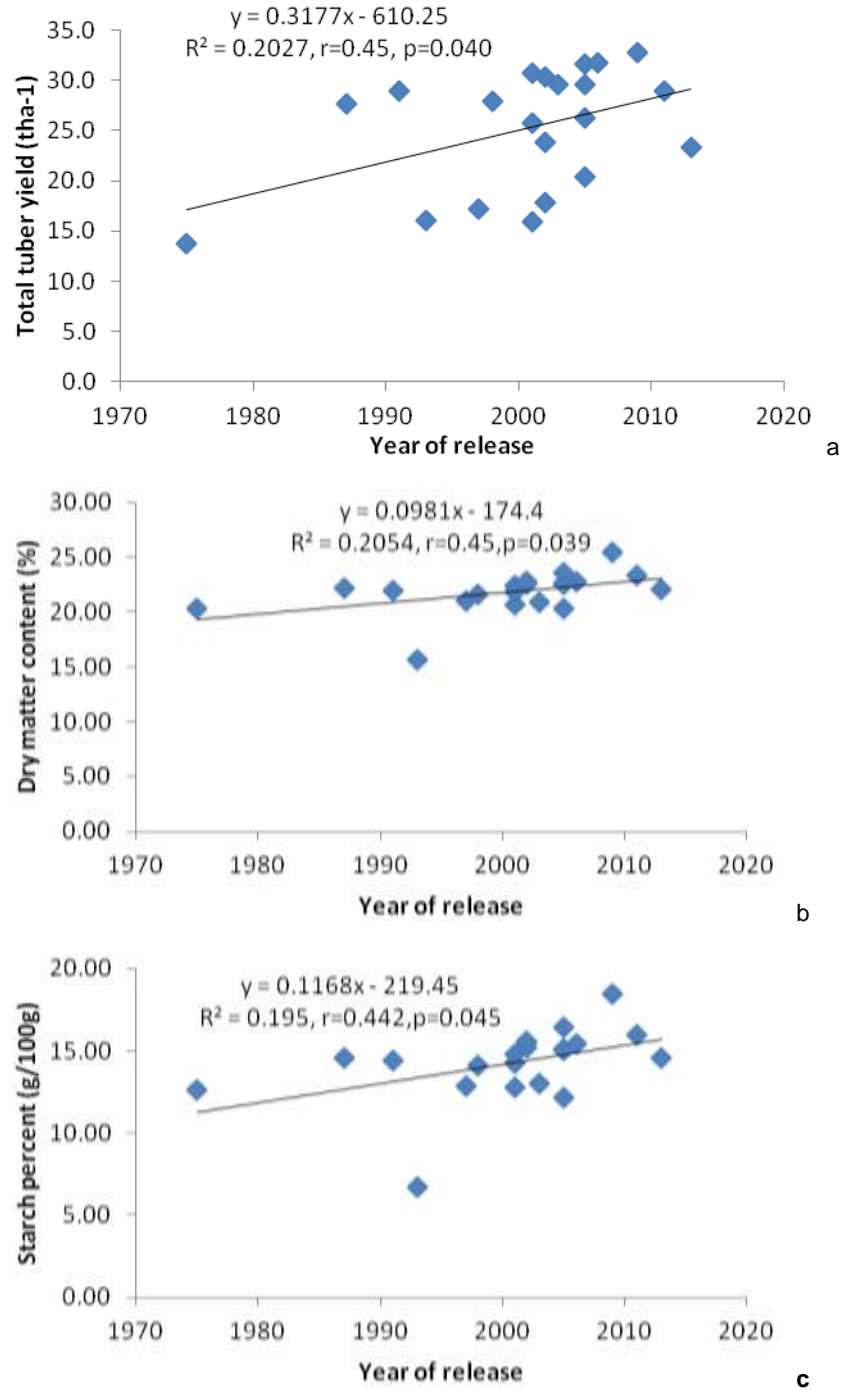
Figure 1. Plot of total tuber yield (t ha^{-1}), dry matter content (%) and starch content (g100 g^{-1}), (a, b and c) of varieties against year of release, respectively.

research institutions and private seed companies since 1987. The analysis of variance revealed the presence of highly significant (P ≤ 0.01) differences between varieties for all traits. There was a considerable variation of yield among improved varieties and farmers` variety (13.8 to 32.8 t ha^{-1}). The improved variety Belete released in 2009 had the maximum yield and maximum mean values for

most tuber's quality traits (specific gravity, dry matter content starch content, and total starch yield), whereas improved variety Menagesha released in1993 had lowest values for yield and other tuber quality traits. Total tuber yield of variety Belete showed yield increment of 137.39 and 0.851% over Nech Abeba (farmers` variety) and the oldest variety (AL-624), respectively. The relative rate of

Table 6. Summary of stepwise regression analysis of mean total tuber yield as dependent variable on independent variables.

	Total tuber yield			
Independent variable	Intercept	Regression coefficient (b)	R^2	VIF
Marketable tuber yield		0.986**	0.972	1.46
Average tuber number	0.377	0.204**	0.978	1.25
Stem number per hill		0.337**	0.982	1.35

**Highly significant difference (p ≤ 0.01), VIF = variance inflation factor.

annual gain was 1.15 and 1.42% year^{-1} for total tuber yield and marketable tuber yield, respectively. The mean total and marketable tuber yields increased over location at the rate of 0.3177 and 0.3401 t ha^{-1}, respectively.

The inconsistency in yield increment among varieties respect with their year of release could be due to variety AL-624 performed well across a wide range of agro ecologie. Attributing on farm productivity to genetic improvement is also more problematic in a vegetatively propagated crop like potatoes than in sexually propagated cereal. The absence of effective seed systems means that a productivity effect from a variety is confounded with the effect of cleaner or physiologically more correct seed (Sarker et al., 2018). The other important reason could be seed degeneration of the varieties due to their different seed sources and recycling the same seed source for subsequent production seasons (Sarker et al., 2018). Seed potato degeneration, the reduction in yield or quality caused by an accumulation of pathogens and pests in planting material due to successive cycles of vegetative propagation had a great influence on the performance of varieties (Thomas-Sharma et al., 2016).

Similar finding was recorded by Wassu (2017) and some recently released varieties showed lower yield performance than the oldest variety (AL-624) in Eastern Ethiopia. The correlation analysis of the potato for total and marketable tuber yield and respective year of variety release had also positive and significant association. Whereas unmarketable tuber yield had negative non-significant correlation value with year of variety release indicating that potato breeders in Ethiopia made some considerable improvement on seed tuber size.

Wassu (2017) recorded the highest estimates for annual genetic gain of total tuber yield (4.05%) in the locality of Hirna with the potato variety Gera and the lowest at Arbarakete for the potato variety Gorebella (-3.02%). Similarly, the variety Chiro at Haramaya had the lowest (-3.43%) and Gera variety at Hirna had the highest (4.94%) genetic gain for marketable tuber yield relative to the oldest variety AL-624. Similar genetic gains were reported by many researchers due to improvements in varieties and agronomic practices (Tamene et al., 2015; CGIAR, 2016). Studies on crop improvement for important agronomic and quality traits were undertaken by different scholars using gene engineering and other breeding methods (Douches et al., 2015; Massa et al., 2015; Liu, 2017).

Conclusion

The study showed that the high annual rates of gain have been achieved in tuber yields and tuber quality related traits through three decades of potato improvement efforts made in the nation though the gain was inconsistent over years of release of varieties and across the centres that developed the varieties. This might be due to different seed generations, variable sources of seeds from different growing and storage conditions and variations in seed physiological status. Therefore, further study is recommended with tissue culture planting materials with no seed degeneration difference among the varieties to isolate the variety effect, tuber seeds of checks has to meet the same health and physiological standards of prospective varieties over major growing areas including all released varieties and farmers cultivars of each growing area, and considering disease reaction and other important agronomic aspects of potato varieties to design appropriate potato improvement strategy in the country.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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