Research Article

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Evaluation of Potato (*Solanum tuberosum* L.) Varieties for Yield and Some Agronomic Traits

https://doi.org/10.1515/opag-2020-0006
received July 9, 2019; accepted October 28, 2019

Abstract: A field experiment was conducted in the central highlands of Ethiopia to evaluate the performance of potato varieties for tuber yield and to identify a superior variety in tuber yield and yield components. The experiment was laid out in a randomized complete block design with three replications at two locations in the central highlands of Ethiopia during the 2017 main cropping season. The results of analysis of variance (ANOVA) showed the presence of highly significant (P<0.01) differences among varieties over all traits studied. The mean squares for location were also significant in indicating the influence of environments on the traits of the studied varieties. However, the interaction between variety and environment had no significant effect on the performances of the potato varieties to attain 50% flowering, specific gravity and dry matter content indicating a similar performance of these traits across all locations. The variety Belete produced the maximum total tuber yield of 32.8 t ha $^{-1}$ and marketable tuber yield of 29.1 t ha $^{-1}$. Conversely, farmers` variety Nech Abeba produced the minimum total tuber yield of 13.8 t ha $^{-1}$ and marketable tuber yield of 8.4 t ha $^{-1}$. For most tuber quality traits, viz., tuber specific gravity, dry matter content, starch percentage and total starch yield, varieties Belete and Menagesha were the maximum and minimum producers, respectively. Thus, it could be concluded that varietal and environmental variations as well as their interaction had considerable influence on tuber yield and the potato's attributes.

Keywords: Potato; Agronomic traits; Growth traits; Released varieties; Central highlands of Ethiopia

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1 Introduction

Potato (*Solanum tuberosum* L.) is a versatile commodity adapted to a wide range of agro-ecologies and there indications of its potential for further expansion in various ecosystems (Burke 2017; CIP 2017). Potatoes can grow from sea level up to 4,700 meters above sea level, from southern Chile to Greenland (CIP 2017). The hilly, fertile terrain of East, Central, West, and Southern Africa, from Ethiopia to the north down to Mozambique on the coastal south, from the volcanic highland regions of the Democratic Republic of Congo, Burundi, and Rwanda, to the highland plateaus of West Africa in Cameroon and Nigeria -these are all home to more than seven million smallholder potato farmer households (Abdulwahab et al. 2016).

Ethiopia has 18 major agro-ecologies (Gebremedhin, 2008). Most of these agro-ecologies have suitable climatic and edaphic conditions for the production of high yield and quality potatoes. About 70% of the cultivated agricultural land is suitable for potato production (Gebremedhin, 2008). Since potato is grown from mid altitudes to very high mountain tops, and from humid to dry areas in the country, improvements in productivity will require the development of varieties best adapted to a wide range of environments (Kolech et al. 2015).

Plant breeding programs primarily focus on improving a crop's adaptability and tolerance to biotic stress in order to increase yield. Crop improvements made since the 1950s coupled with inexpensive agronomic inputs, such as fertilizers, pesticides, and water have allowed agricultural production to keep pace with human population growth (Brummer et al. 2011). In Ethiopia, a number of improved potato varieties have been released by different research institutions; with major emphasis to wide adaptability, high tuber yield and late blight resistance (Asefa et al. 2016). Since the registration of the first potato variety (AL-624) in 1987, more than 36 potato varieties were released by the research centers, higher learning institutions and private companies (Gebremedhin 2013; MANR 2016). However, the performance of these varieties under a common set of environments was not studied and documented (Amdie et al. 2017) since they were released by different institutions and also recommended for different agro-ecologies. Thus, it is crucial to evaluate these varieties under the same set of environment and identify high yielding varieties under Central Ethiopia's environmental conditions.

2 Materials and methods

2.1 Description of the Study Sites

The experiment was carried out under rain fed conditions at two locations; Holetta Agricultural Research Center and Adea Berga sub-station during the 2017 cropping season.

2.2 Description of Experimental Materials

The experiment was conducted using 20 improved and one farmer's variety widely preferred by consumers (Table 2).

2.3 Treatments and Experimental Design

The experiment was laid out in a randomized complete block design with three replications. The experimental plot size was 10.8 m^2 planted with 4 rows spaced 0.75 m to each other and 0.30 m plant to plant spacing in a row. The spaces between blocks and plots were 1.5 m and 1 m, respectively.

2.4 Experimental Procedures

The experimental field was prepared in accordance with a standard practice used by Holetta Research Centre (Lemaga et al. 1992). The land was disk ploughed, harrowed, and leveled with a tractor. Then ridging was done by hand. Fertilizer was applied at the rate of 110.81 kg N, 90.06 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 were conducted based on the recommendations of Holetta Research Centre (Lemaga et al. 1992).

2.5 Data Collection and Measurement

Days to flowering: was recorded when 50% of the plant populations in each plot bloomed.

Days to physiological maturity: was recorded when the haulms (vines) of 50% of the plant population per plot turned yellowish or showed senescence.

Number of leaves plant^{-1}: The number of leaves per plant were determined by counting the number from ten plants (hills) in each plot before the start of tuber formation and averaged.

Plant height (cm): was taken as the average of ten plants height per plot measured from the soil surface to the top-most growth point of plants.

Number of main stem/hill: data on this parameter was recorded as the average stem number counted from ten hills per plot at 50% flowering. Only stems that had directly grown from the mother tuber and acted as an independent plant above the soil were considered as main stems. Stems branching from other stems above the soil were not considered as main stems (Lung`aho *et al.*, 2007).

Average tuber number/hill: was recorded at harvest as the actual number of tubers collected from 20 middle row plants in each plot and calculated as an average tuber number.

Average tuber weight (g/tuber): was determined by dividing the total fresh tuber yield to their respective total tubers number.

Total tuber yield (t ha^{-1}): was calculated as the sum of the weights of marketable and unmarketable tubers from the net plot area and transformed to ton per hectare.

Marketable tuber yield (t ha^{-1}): was calculated by weighing all the tubers which were free from defects, disease, crack, and other physiological disorders and not

Table 1: Description of the study areas

Location	Latitude	Longitude	Altitude (M.a.s.l)	Mean annual rain fall (mm)	Mean annual temperature (0C)
HARC	09^{0} 00' N	38^{0} 29' E	2400	1100	14.15
Adea Berga Sub-station	09^{0} 16' N	38^{0} 23' E	2500	1225	18.0

Source: HARC (Holetta Agricultural Research Centre), 2010

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

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

underweight per net plot area and converting into ton per hectare.

Unmarketable tuber yield (t ha^{-1}): Was calculated by weighing all tubers other than marketable from each plot and converting in to ton per hectare bases.

Specific gravity: This was determined by weighing 5 kg of tubers in the air and then in water method (Gould, 1995) and calculated as follows:

Specific gravity = (weight in air) / (weight in air – weight in water).

Tuber dry matter content: This was determined by chopping five tubers into 1-2 cm small cubes and drying two sub-samples of 200g each taken from thoroughly mixed chopped tubers in an oven set at 80˚C for 72 hours in two paper bags until a constant weight is reached. Then the percentage of dry matter content for each variety was calculated as suggested by CIP (2007) using the following formula:

Dry matter% = (dry weight / fresh weight) x 100

Tuber starch content (g/100g): The percentage of starch content was calculated from the specific gravity using the following formula:

Starch (%) = 17.546+199.07 x (specific gravity-1.0988) (Talburt and Smith 1959)

Specific gravity was determined as indicated above by the weight in air and weight in water method.

Total starch yield (t ha^{-1}): was calculated by multiplying the total tuber yield by the starch content measured as g/100g tuber.

2.6 Data Analysis

All data were subjected to separate analysis of variance (ANOVA) of individual locations and a combined ANOVA over locations using SAS software version 9.3 (SAS Institute 2010) using a general linear model (GLM) (Gomez and Gomez 1984).

The combined analysis of variance over locations were computed after a homogeneity test of error variances using F- test as stated by Gomez and Gomez (1984). The error variances ratio was computed by dividing the higher error mean square by the smaller error mean square, and the error variances were considered as homogeneous if the ratio was not greater than three. In case of only two variances (two locations or seasons), the F-test or F-max method is better to check variances in homogeneity (Hartley 1950). The results of the two locations' homogeneity test of error variances indicated the homogeneity of error variances for all traits and accordingly the comparison of varieties was conducted based on pooled mean performance over the locations using Duncan's Multiple Range Test (DMRT) at a 5% level of significance.

Analysis of variance in randomized complete block design was computed using the following model:

$Yij = \mu + rj + gi + \varepsilon ij$

Where, Yij = the response of trait Y in the i^{th} genotype and the j^{th} replication

μ = the grand mean of trait Y
rj = the effect of the j^{th} replication
gi = the effect of the i^{th} genotype
εij = experimental error effect

3 Results

3.1 Analysis of variance

The results of analysis of variance (ANOVA) showed that the varieties had highly significant (P<0.01) differences for all traits. Therefore, combined analysis of variance over locations was performed for all traits. The results of this ANOVA revealed significant mean squares of variety and location for all traits except the mean squares of location for days to 50% flowering. The mean squares for genotype x location (G x L) were significant for all traits except for days to 50% flowering, specific gravity and dry matter content (Table 5), indicating the consistent performance of the varieties across the two locations. This might be due to the past breeding efforts made to develop varieties that have relative consistency on these traits over a wide range of environments.

3.2 Mean performance of varieties for phenology and growth traits

Significant variation for most phenology and growth traits was observed among potato varieties (Table 3). The potato varieties took 51 days (Menagesha) to 65.2 days (Bubu) to

Table 3: Mean squares from combined analysis of variances over locations for 14 traits of 21 potato varieties in 2017

Trait	Rep (L) (4)	Variety (V) (20)	Location (L) (1)	L x V (20)	Error (80)	CV (%)
Days to 50% flowering	10.01	61.24**	5.37	0.82	9.68	5.22
Days to physiological maturity	49.25	160.96**	1176.36**	103.82**	10.72	3.30
Number of leaves per plant	8.76	219.16**	3618.22**	117.17**	16.31	9.89
Plant height(cm),	138.97	635.76**	18112.81**	120.05**	16.46	6.84
Stem number per hill	1.15	8.53**	65.29**	2.90**	0.24	11.12
Average tuber number per hill	4.96	25.15**	48.52**	16.72**	2.26	13.35
Average tuber weight(g)	21.24	600.91**	4538.05**	378.75**	21.27	8.95
Total tuber yield (t ha^{-1})	16.99	218.57**	2556.72**	49.37**	4.39	8.29
Marketable tuber yield (t ha^{-1})	15.02	205.99**	1927.87**	44.39**	3.82	9.13
Specific gravity	0.0002	0.0004**	0.008**	0.00005	0.00004	0.61
Dry matter content (%)	2.14	20.54**	321.44**	2.23	1.50	5.60
Starch content percent	5.62	30.67**	284.76**	4.64*	2.35	10.74
Total starch yield (t ha^{-1})	1.15	8.13**	9.81**	1.03**	0.20	12.36

*, **, significant at P=0.05 and P<0.01, respectively. Rep= replication, CV (%) = coefficient of variation in percent, numbers in the parenthesis are degrees of freedom.

attain 50% flowering, while from 91.0 days (Awash) to 108 days (Marachere) days to reach physiological maturity ranged (Table 4). Six varieties (Guassa, Zemen, Wechecha, Awash, Bedassa and Nech Abeba) had statistically similar days to 50% flowering to Bubu but significantly different from other varieties. Three varieties Challa, Bubu and Belete had delayed maturity without significant differences between each other and Marachere.

Six varieties (Bedassa, Chiro, Wechecha, AL-624, Gabissa and Nech Abeba) showed medium maturity without significant difference from Awash but significant difference with other varieties.

Means followed by the same letter/s in each column are not significantly different at P= 0.05 according to Duncan's Multiple Range Test. DF= days to 50% flowering, DM= days to physiological maturity, NLP= number of leaves per plant, PH (cm) = plant height and SN= stem number per hill.

From the combined analysis of variance, the maximum and minimum number of leaves per hill were recorded from the varieties Shenkolla and Menagesha (51.9 cm and 30.5cm), respectively (Table 4). Shenkolla had maximum number of leaves per plant with no significant difference from Gudene and Gorebella but had a significantly different number from other varieties. Four varieties (Marachere, Guassa, Chiro and Awash) had the minimum number of leaves per plant with no significant difference from Menagesha but significantly different from other varieties (Table 4).

From the combined analysis of variance, the maximum plant height was recorded from Gorebella (74.2 cm) whereas the minimum plant height was recorded from Menagesha (38.9 cm) with an average value of 59.36 cm (Table 4). Gorebella had a statistically non-significant plant height compared to Gudene, Gera and Shenkolla but significantly different from other varieties. Variety

Table 4: Mean performances of 21 potato varieties for phenology and growth traits evaluated at Holetta and Adea Berga in 2017

	Traits				
Variety	**DF**	**DM**	**NLP**	**PH (cm)**	**SN**
Dagim	59.7^{b-f}	102.0^{cd}	41.4^{cde}	57.0^{fg}	4.1^{ef}
Bubu	65.2^{a}	105.2^{abc}	40.5^{ef}	66.8^{bc}	5.9^{c}
Belete	57.7^{d-g}	104.3^{a-d}	43.1^{cde}	67.3^{bc}	4.4^{de}
Gudene	60.7^{b-e}	96.0^{fg}	50.5^{ab}	71.6^{ab}	6.5^{b}
Challa	56.3^{fg}	107.2^{ab}	41.5^{cde}	61.5_{def}	3.0^{fg}
Marachere	56.7^{efg}	108.0^{a}	34.4^{gh}	42.0^{ij}	2.8^{hi}
Shenkolla	61.0^{bcd}	103.2^{bcd}	51.9^{a}	69.2^{ab}	7.3^{a}
Gabissa	59.8^{b-f}	$93.7f^{gh}$	35.9^{fg}	60.5^{ef}	5.4^{c}
Gera	58.0^{c-g}	101.3^{cd}	45.7^{b-e}	71.5^{ab}	4.3^{de}
Jalene	57.7^{c-g}	97.0^{ef}	45.4^{b-e}	52.9^{gh}	4.5^{de}
Gorebella	54.7^{g}	100.3^{de}	46.6^{ab}	74.2^{a}	4.8^{d}
Guassa	62.2^{abc}	101.0^{cde}	34.6^{gh}	44.3^{i}	3.2^{gh}
Zengena	60.8^{b-f}	103.5^{bcd}	44.4^{cde}	63.2^{cde}	3.3^{gh}
Zemen	62.5^{ab}	100.3^{de}	42.0^{cde}	66.6^{bcd}	5.7^{c}
Bedassa	61.8^{a-d}	92.0^{gh}	41.2^{cde}	57.4^{fg}	4.1^{def}
Chiro	60.7^{b-e}	95.0^{fgh}	31.5^{gh}	63.9^{cde}	4.1^{def}
Wechecha	61.7^{a-d}	93.3^{fgh}	35.8^{fg}	45.0^{i}	4.5^{de}
Menagesha	51.0^{h}	100.3^{de}	30.5^{h}	38.9^{j}	2.5^{i}
Awash	61.3^{a-d}	91.0^{h}	32.8^{gh}	50.7^{h}	3.4^{gh}
AL-624	60.7^{b-e}	93.3^{fgh}	46.1^{bcd}	63.2^{cde}	4.5^{de}
Nech Abeba	63.2^{ab}	93.8^{fgh}	40.7^{def}	58.9^{ef}	4.5^{de}
Grand Mean	59.63	99.14	40.79	59.36	4.43

Menagesha had a statistically different plant height from all other varieties except that of Marachere . Stem numbers per plant were also significantly influenced by both variety and location (Table 4). Accordingly, the Shenkolla variety produced the maximum stem number per plant (7.3) which is statistically different from all other varieties. The minimum stem number per plant (2.5) was recorded from the variety Menagesha which was statically different from all other varieties but Marachere.

3.3 Mean performance of varieties for yield components and yield

The results of the pooled analysis of variance showed a highly significant difference among the studied varieties in the average tuber number per hill. The maximum and minimum average tuber number per plant was recorded from the Bedassa variety (15.7) and Guassa (7.3), respectively (Table 5). Guassa had the lowest average tuber number per hill which is not significantly different from Menagesha and the recent variety Dagim but different from other varieties. Bedassa also had no significant difference from the Gudene variety but was significantly different from other varieties.

The average tuber weight (g/tuber) varied highly significantly ($P \leq 0.01$) across varieties, locations and their interaction. From the combined analysis of variance the maximum and minimum average tuber weight (g/tuber) was recorded from the Dagim variety (70.0) and Marachere (35.6), respectively. Dagim had a non-statistical different value from varieties Belete and Gorebella but was statistically different from other varieties. Marachere also didn't have a statically significant average tuber weight from the Wechecha and Zengena varieties (Table 5).

The result of the combined analysis of variance revealed the presence of highly significant total tuber yield differences among the varieties studied over locations and

Table 5: Mean performances of 21 potato varieties for tuber yield and yield related traits evaluated at Holetta and Adea Berga in 2017

		Traits			
Variety	**ATN**	**ATW**	**TTY**	**MTY**	**UMTY**
Dagim	8.1^{hi}	70.0^{a}	23.4^{i}	19.9^{e}	3.5^{fgh}
Bubu	11.9^{cde}	54.6^{cde}	$28.9^{c\text{-}f}$	24.7^{cde}	4.3^{def}
Belete	10.9^{ef}	65.0^{ab}	32.8^{a}	29.1^{a}	$3.8^{e\text{-}h}$
Gudene	14.6^{ab}	48.6^{efg}	31.8^{ab}	26.3^{bc}	5.6^{a}
Challa	10.6^{efg}	56.1^{cd}	26.3^{fgh}	23.4^{de}	2.9^{hij}
Marachere	10.6^{efg}	35.6^{j}	20.4^{j}	17.3^{gh}	$3.1^{g\text{-}j}$
Shenkolla	13.2^{bcd}	50.1^{def}	$29.6^{b\text{-}e}$	24.1^{cde}	5.5^{ab}
Gabissa	13.4^{bc}	53.7^{cde}	31.6^{abc}	27.3^{ab}	4.3^{cde}
Gera	10.7^{efg}	64.1^{b}	$29.6^{b\text{-}e}$	27.2^{ab}	2.4^{jk}
Jalene	$11.5^{c\text{-}f}$	44.6^{fgh}	23.8^{hi}	19.1^{fg}	4.7^{bcd}
Gorebella	9.5^{fgh}	66.9^{ab}	$30.4^{a\text{-}d}$	27.4^{ab}	$3.1^{g\text{-}j}$
Guassa	7.3^{i}	58.5^{c}	17.8^{k}	15.1^{hi}	2.6^{ijk}
Zengena	9.5^{fgh}	36.5^{ij}	15.9^{kl}	12.4^{j}	$3.5^{e\text{-}h}$
Zemen	$11.4^{c\text{-}f}$	44.1^{gh}	25.8^{ghi}	22.1^{e}	$3.6^{e\text{-}h}$
Bedassa	15.7^{a}	44.5^{fgh}	$30.7^{a\text{-}d}$	25.6^{bcd}	5.0^{abc}
Chiro	13.1^{bcd}	52.0^{de}	$28.1^{d\text{-}g}$	24.9^{bcd}	3.2^{ghi}
Wechecha	11.3^{def}	35.7^{j}	17.2^{k}	13.3^{ij}	3.9^{efg}
Menagesha	8.8^{ghi}	53.7^{cde}	16.1^{kl}	13.9^{ij}	2.1^{k}
Awash	12.2^{cde}	54.2^{cde}	$28.9^{c\text{-}f}$	23.8^{cde}	5.1_{abc}
AL-624	11.6^{cde}	52.6^{cde}	27.7^{efg}	23.9^{cde}	$3.7^{e\text{-}h}$
Nech Abeba	10.7^{efg}	41.5^{hi}	13.8^{l}	8.4^{k}	5.4^{ab}
Grand Mean	11.26	51.55	25.26	21.39	3.87

Means followed by the same letter/s in each column are not significantly different at p= 0.05 according to Duncan's Multiple Range Test. ATN= average tuber number per hill, ATW= average tuber weight (g/tuber), TTY= total tuber yield ($t\ ha^{-1}$), MTY= marketable tuber yield ($t\ ha^{-1}$), UMTY= unmarketable tuber yield ($t\ ha^{-1}$).

location by variety interaction (Table 5). The Belete variety produced the maximum (32.8 t ha^{-1}) total tuber yield while the farmers` variety Nech Abeba produced the lowest total tuber yield (13.8 t ha^{-1}) (Table 5). Maximum and minimum unmarketable tuber yield was recorded from the Gudene (5.6 t ha^{-1}) and Menagesha (2.1 t ha^{-1}) varieties respectively.

3.4 Mean performance of varieties for tuber quality related traits

With regard to potato specific gravity, there were no significant variety x location interactions, but the main effects of both variety and locations were highly significant (Table 6). From the pooled analysis of variance, high tuber specific gravity was recorded from Belete (1.102) which was statistically different from all other potato varieties and the lower tuber specific gravity was recorded from Menagesha (1.057). The Menagesha variety also had a significantly different specific gravity value from all other varieties (Table 6).

Like specific gravity, tuber dry matter content was also significantly influenced by both variety and growing environment but not their interaction effect. Among the varieties studied, the maximum dry matter percentage was recorded from the Belete variety (25.417) followed by Challa (23.625) while the minimum dry matter percent was recorded from the Menagesha variety (15.708). Both Belete and Menagesha had statistically different dry matter content from all other varieties. Based on the pooled analysis of variance, the starch content percentage (g $100g^{-1}$) of potato differed significantly across growing environment, variety and their interaction (Table 6). Belete generated the maximum starch percentage (18.43%) while Menagesha had the lowest starch percentage (6.70%) (Table 6).

Table 6: Mean performances of 21 potato varieties for tuber quality traits evaluated at Holetta and Adea Berga in 2017

		Traits		
Variety	**SG**	**DMC**	**SC**	**TSY**
Dagim	1.087^{bcd}	$22.042^{b\text{-}g}$	$14.537^{b\text{-}f}$	3.378^{fg}
Bubu	1.092^{b}	23.375^{bc}	15.982^{bc}	4.520^{bcd}
Belete	1.102^{a}	25.417^{a}	18.430^{a}	5.887^{a}
Gudene	1.090^{bcd}	22.833^{bcd}	15.397^{bc}	4.815^{b}
Challa	1.092^{b}	23.625^{b}	16.408^{b}	4.203^{cde}
Marachere	1.080^{d}	20.292^{i}	12.172^{g}	2.423^{h}
Shenkolla	1.087^{bcd}	$22.625^{b\text{-}e}$	15.117^{bc}	$4.330^{b\text{-}e}$
Gabissa	1.088^{bcd}	$22.500^{b\text{-}f}$	15.018^{bcd}	4.663^{bc}
Gera	1.082^{cd}	$20.917^{f\text{-}i}$	$12.993^{d\text{-}g}$	3.812^{efg}
Jalene	1.090^{bc}	22.792^{bcd}	15.560^{bc}	3.558^{fg}
Gorebella	1.089^{bc}	$22.583^{b\text{-}e}$	15.217^{bc}	4.585^{bc}
Guassa	1.090^{bc}	22.833^{bcd}	15.475^{bc}	2.635^{h}
Zengena	1.088^{bcd}	$21.875^{c\text{-}i}$	$14.275^{c\text{-}f}$	2.260^{hi}
Zemen	1.087^{bcd}	$22.417^{b\text{-}f}$	$14.822^{b\text{-}e}$	3.797^{efg}
Bedassa	1.082^{cd}	20.625^{ghi}	12.770^{efg}	3.812^{efg}
Chiro	1.083^{bcd}	$21.625^{d\text{-}i}$	$14.108^{c\text{-}g}$	3.845^{efg}
Wechecha	1.082^{cd}	$21.042^{e\text{-}i}$	12.857^{efg}	2.205^{hi}
Menagesha	1.057^{e}	15.708^{j}	6.700^{h}	1.068^{j}
Awash	1.088^{bcd}	$21.958^{b\text{-}h}$	$14.397^{b\text{-}f}$	$4.098^{c\text{-}f}$
AL-624	1.088^{bcd}	$22.250^{b\text{-}g}$	$14.587^{b\text{-}f}$	3.997^{def}
Nech Abeba	1.080^{d}	20.375^{hi}	12.607^{fg}	1.747^{i}
Grand Mean	1.09	21.89	14.26	3.60

Means followed by the same letter/s in each column are not significantly different at p= 0.05 according to Duncan's Multiple Range Test.
SG= specific gravity(gcm^{-3}), DMC= dry matter content (%), SC= starch content percent(g $100g^{-1}$), TSY= total starch yield (t ha^{-1}).

Regarding total starch yield (tha^{-1}), all potato varieties showed a highly significant difference over locations and interacted highly significantly within locations indicating their inconsistent performance across the tested locations (Table 6). The Belete variety produced the highest starch yield (5.887 t ha^{-1}) while the Menagesha produced the least (1.068 t ha^{-1}) starch yield. The Belete variety had a total starch yield of 6.60 and 5.17 t ha^{-1} at Holetta and Adea Berga while Menagesha had 1.10 and 1.04 t ha^{-1} total starch yield at these locations, respectively.

4 Discussion

The presence of highly significant differences among potato varieties suggested the presence of sufficient genetic differences that might be related to the wide range of parental backgrounds used in the development of these varieties over years. The presence of genetic differences among potato varieties for marketable tuber yield, total tuber yield and late blight disease resistance among 17 potato varieties in Ethiopia has also been reported (Wassu 2017). Habtamu et al. (2016a,b,c) also reported similar significant differences among genotypes in their phenological and growth traits, tuber yield, tuber physical, internal and chips making quality traits from the evaluation of 16 potato genotypes, including two farmers` varieties in eastern Ethiopia.

The significant mean squares for location being significant are also clear evidence for the significant influence of the varying environment on the studied traits of potato varieties. However, the interaction of variety x environment had no significant effect on the performances of varieties in days to 50% flowering, specific gravity and dry matter content showing the consistent performance of varieties in these traits across locations. The performances of varieties for the remaining traits were influenced by the the interaction of variety x environment which suggested that the varieties had a differential response at each location. Elfinesh et al. (2011) reported a similar significant influence of growing environment, genotypes and their interaction on some quality traits of potato in Eastern parts of Ethiopia. The other study by Tesfaye et al. (2012) reported the significant effect of genotype, location and genotype × environment interactions on dry matter content, starch content and starch yield of 25 potato varieties studied in Northern parts Ethiopia. Similar results were reported by different scholars on potato (Abbas et al. 2011; Asefa et al. 2016; Wassu 2016; Matin et al. 2017; Nasiruddin et al. 2017).

4.1 Mean performance of varieties for phenology and growth traits

The varieties Bedassa, Chiro, Wechecha, AL-624, Gabissa and Nech Abeba and three other varieties matured in less than 100 days and could be grouped under early maturity varieties according to the Acquisition and Distribution Unit (2009) and Mihovilovich et al. (2014) maturity classes. Based on other study carried by Kolech et al. (2017) most of the varieties included in this study were grouped in to early and medium early maturity classes. Some of the potato varieties had variations for flowering and maturity at the two locations but a few varieties such as Bubu and Menagesha showed stability for days to 50% flowering. Generally, 9 (42.86%) and 12 (57.14%) varieties had <100 and 100 to 108 days to maturity which could be grouped under early and intermediate maturity varieties (Mihovilovich et al. 2014). Days to 50% flowering and days to physiological maturity at individual locations ranged from 51.0 to 65.6 and 82.2 to 107.0 at Holetta and 51.0 to 65.0 and 96.7 to 109.3 at Adea Berga, respectively. In Agreement with the present study, Tesfaye *et al*. (2012) reported that the Awash variety was an early maturing type taking only 89 days and farmers` cultivar (Agere) 108 days to maturity in Northern Ethiopia.

Potato varieties *viz*. Marachere, Guassa, Chiro and Awash had the minimum number of leaves per plant. Masarirambi et al. (2012) and Zebenay (2015) reported the significant influence of numbers of leaves were significantly influenced by plant population density or spacing and seed size on number of leaves per plant in Zimbabwe and at central highlands of Ethiopia, respectively. The result in the present study is expected as genotypes normally differ genetically in their growth habit and stem height which will have an effect on the number of leaves per plant.

Berhanu and Tewodros (2016) reported a highly significant ($P < 0.01$) effect of environments, cultivar and their interaction on plant height in Eastern Ethiopia. Zerihun (2016) also reported that there was substantial variability in plant height among potato genotypes and growing environments in northern Ethiopia. These differences in plant height among the varieties may be caused by plant genetics and the quality of the plant material (Eaton et al. 2017) and responses of the cultivars to the growing environments. Seed tuber size, environmental variations and genetic factors of the varieties and agronomic practices viz. mother tuber size, plant spacing also had a significant influence on stem number (Masarirambi et al. 2012; Zebenay 2015; Eaton et al. 2017).

4.2 Mean performance of varieties for yield components and yield

The results of separate analyses of variance revealed that highest average tuber number was recorded from variety Bedassa at Adea Berga and lowest tuber number was recorded from farmers` cultivar (Nech Abeba) at Holetta. Habtamu et al. (2016c) and Berhanu and Tewodros (2016) also reported a significant variation between varieties, growing environment and their interaction in potato for average tuber number per hill in Eastern Ethiopia. Seifu and Betewulign (2017) similarly reported a significant difference in tuber numbers per hill among 5 potato varieties in southern Ethiopia.

From the results of the present study, growing environment and genotype variation had an influence on tuber weight. According to Habtamu et al. (2016c) average tuber weight was highly influenced by potato genotypes, location and their interaction in Eastern Ethiopia. Zerihun (2016) also reported the presence statistically significant difference among sixty potato genotypes evaluated in Northern Ethiopia under stress and non-stress conditions. Variation among different varieties in the weight of tubers per plant may be due to the genetics, management practices, the seed quality, or the agro-ecological conditions of the experimental sites (Eaton et al. 2017).

From separate analysis of individual location, variety Belete and Nech Abeba produced a maximum (40.5 t ha^{-1}) and minimum tuber yield (13.6 t ha^{-1}) at Holetta. In the same manner the varieties Gorebella and Marachere produced the highest (27.9 t ha^{-1}) and lowest total tuber yield (12.6 t ha^{-1}), respectively at Adea Berga. Hence, varieties showed an inconsistent tuber yield performance at different locations. This might be due to the genetic makeup of varieties or effects of environmental factors. Four varieties (Gudene, Gabissa, Gorebella and Bedassa) had a maximum total tuber yield that is not significantly different from the high yielder variety Belete but significantly different from other varieties. Two other varieties (Zengena and Menagesha) had low total tuber yield that are not significantly different from the low yielder (Nech Abeba) but significantly different from other varieties.

Habtamu et al. (2016c) reported a total tuber yield variation of 18.34 to 48.29, 26.71 to 43.50 and 17.70 to 56.52 t ha^{-1} at Haramaya, Arbarakete and Hirna, respectively in Eastern Ethiopia. Similar tuber yield variation results were reported on potato by different scholars in Ethiopia (Zebenay 2015; Wassu 2016; Seifu and Betewulign 2017). In addition to the genetic makeup of the varieties, differences in tuber size, plant spacing and others could have contributed to the observed yield variations among varieties and environments (Masarirambi et al. 2012).

4.3 Mean performance of varieties for tuber quality related traits

Wassu (2016) and Berhanu and Tewodros (2016) reported a statistically significant effect of varieties on tuber specific gravity. However, locations and the interaction effect of cultivar and location was not statistically significant, indicating the consistency of this trait across different locations. Furthermore, Berhanu and Tewodros (2016) also reported the statistically significant influence of the interaction of cultivar by location, but not location. The Belete variety was the highest in tuber specific gravity in both growing areas with 1.109 at Adea Berga and 1.094 at Holetta. Measurement of specific gravity of potatoes has been widely used as a tool for quick estimation of dry matter and starch content in potato tuber lots (Kaur and Aggarwal 2014). Good quality potatoes should have a specific gravity value of more than 1.080. Based on this suitability cut-off point value, all potato varieties except the variety Menagesha could be used for processing purposes. Potato tubers with specific gravity values less than 1.070 are generally unacceptable for processing (Kabira and Berga 2003; CIP 2007). The difference might be due to genetic and environmental variations (Tesfaye et al. 2013). Chemeda et al. (2014) also reported that tuber specific gravity is highly influenced by varietal difference and storage duration.

The present investigation showed that the growing environment had an influence on tuber dry matter content to a certain extent. This result agreed with the study result reported by Tesfaye et al. (2013) who confirmed the increment of dry matter content of potato as the altitude of the growing environment goes up. A previous study of Wassu (2016) revealed that the Belete variety had a maximum dry matter percentage over three locations for three cropping seasons among 17 potato genotypes evaluated. Similarly, Berhanu and Tewodros (2016) reported that tuber dry matter percentage is significantly influenced by growing environment, cultivars and their interaction in eastern Ethiopia. In another study Habtamu et al. (2016b) reported that tuber dry matter content is influenced by both genotypes and environments but not by the interaction of genotypes and growing environment.

Abbas et al. (2011) elucidated that tuber dry matter content is strongly governed genetically governed characteristic and differs significantly among cultivars. Dry matter content is an important quality determinant in potato processing and its higher content (>20%) helps in reduced oil uptake during frying, desirable texture and enhanced yield in the finished products (CIP 2007). Dry matter content is categorized as high (>23%), medium (20-23%) and low (<20%) according to the Acquisition and Distribution Unit of CIP (CIP 2009). Potatoes with a dry matter content of 20-24% are ideal for making French fries while those with a dry matter content of 24% are ideal for preparing crisps (Kabira and Berga, 2003). From the varieties tested in the present study, all the varieties except Menagesha could be used for processing purposes as their dry matter content value is greater than the minimum acceptable limit for processing qualities (>20%) (Acquisition and Distribution Unit 2009).

Both the higher as well as the lower starch yielder varieties were statistically different from all other varieties and each other. This result is in agreement with Wassu (2016) who reported the Belete variety as the highest starch containing variety over 16 genotypes studied for three seasons over three locations in eastern Ethiopia. Habtamu et al. (2016b) evaluated 18 potato genotypes at three different locations of eastern Ethiopia and reported that the starch content was influenced by potato genotypes growing environment and their interactions.

Although starch content has a strong genetic basis, a significant portion of the variation is due to the maturity length of the potato plant. Late maturing cultivars tend to have a higher starch yield than early ones (Van Eck 2007). Potatoes with higher starch content are well suited for food use, processing or starch manufacturing. In this association, Esendal (1990) suggested that starch content values are categorized into four groups: the highest starch content (contents higher than 19.0%, mashing), high starch content (contents between 16.0 and 19.0%, roasting), intermediate starch content (contents between 13.0 and 15.9%, cooking or roasting), and low starch content (contents to 12.0%, boiling). According to this classification, 13 of the potato varieties evaluated in the present study belong to the intermediate starch content group and only two varieties (Belete, and Challa) belong to the high starch content group. Conversely, the Menagesha variety placed on the last range is placed in low starch content group. Regarding total starch yield (tha^{-1}), all potato varieties showed a highly significant difference over locations and the interaction of variety by location (Table 5).The high performance of the Belete variety for all quality traits could be the genetic potential of the variety as evidence from the international potato Centre (CIP). Belete variety was released for processing purpose with good chips and crisp (French fries) quality (Acquisition and Distribution Unit 2009). Tesfaye et al. (2012) reported a highly significant genotypic, location and location x genotype mean squares for starch yield among 25 potato genotypes evaluated at three varying locations in Northwestern parts of the country.

5 Conclusion

In conclusion, the present study revealed the existence of significant variability among released potato varieties in their tuber yield and other yield related traits. This suggested the higher chance of using these genotypes to improve tuber yield and other important agronomic or quality traits in the crossing program. Finally, it could be concluded that varietal and environmental variations as well as their interaction had a considerable influence on yield and its potato attributes. Hence, varietal evaluation of potato at a certain time interval for tuber yield and other important traits should be part of the national potato research program in the country to identify potential varieties that perform better under a wide range of the country's agro-ecological areas and also the desirable parental variety for the crossing program.

Acknowledgements

The authors are highly grateful for the staff members of horticulture research and administration at Holetta research Centre for their valuable support and the Ethiopian Institute of Agricultural Research for funding the field experiment work.

Conflict of interest: Authors declare no conflict of interest.

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