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Evaluation of tuber quality, yield and yield related traits of potato (*Solanum tuberosum* L.) genotypes at Holetta, Central Ethiopia

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Abstract

In Ethiopia, potato is a food security and income generating crop for millions of smallholder farmers. Previous research efforts related to variety development was focusing on tube yield and late blight resistance with wide adaptability. So far, the potato research program in the country however, devoted less on tuber quality traits and processing parameters except few recently released varieties that considered tuber quality traits for processing. These few potato varieties with processing qualities not yet satisfied the ever-emerging processing industries for chips and French fries in the country. Hence, this study aimed to seek evaluating more potato genotypes that have merits for tuber quality traits used for processing and yield attributes. The experiment was laid out in a randomized completed block design with three replications using 24 potato genotypes to evaluate the processing quality traits of advanced potato genotypes at Holetta Agricultural Research Centre in 2017 main cropping season. The results of the analysis of variance revealed that all the traits showed significant differences among the genotypes indicating there is wide genetic variation. The highest and significantly different tuber physical quality traits of geometric mean diameter and surface area was recorded from CIP395017.229, sphericity of the tuber from CIP396027.205, and length to width ratio from CIP399075.7. The specific gravity of tubers, dry matter content and total starch content also ranged from 1.070 to 1.103 gcm^{-3}, 18.67 to 25.75%, and 12.64% to 18.95%, respectively. The five advanced genotypes CIP398098.65, CIP392617.54, CIP398190.404, CIP394611.112, and C398190.89 were selected for their high total tuber yields over 36.80 t/ha, with more than 31.47 t/ha marketable tuber yield, greeter than 69.92 g/tuber average tuber weight, higher than 58.41 mm^3 geometric mean diameter, more than 21.25% dry matter content, excellent tuber characteristics and processing quality traits for chips and French fries making. From this study, selection of potato genotypes that consider both external and internal tuber quality traits would expedite the process of advancing ample potato varieties with processing qualities in the country considering comprehensive study by including more potato genotypes across wider growing environments.

Keywords Tuber quality, Processing quality traits, French fries, Chips, Potato genotypes

Introduction

In Ethiopia, potato is a food security and income generating crop for millions of smallholder farmers. The crop is among a food security commodity for rural inhabitants in the country, especially during food scarce months when most cereal crops are not ready to harvest. Ethiopia is one of the most potential Sub-Sahara African countries blessed with its 70% conducive agroecology for potato

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production (Gebremedhin 2008). Since the start of the first organized potato research and development in the country in 1975, the potato research program made a tremendous effort to improve the production and productivity of the crop. In Ethiopia, potato stands top in the list among other horticultural crops and root and tuber crops. During the main rainy season alone it was grown by over 1.12 million households on an area of over 78,000 hectares of land. Over 65% percent of this produce is being utilized for household food purpose while nearly 20% is marketed as income source (ESS 2022).

Compared to other food crops, potatoes offer more nutrient-dense (carbohydrates, proteins, minerals, dietary fiber, and a negligible amount of fat) food per unit of land, time, and adverse conditions (Horton 1987; Gumul et al. 2011). It is among the most productive crops in terms of converting natural resources into high-quality food, yielding large quantities, and responding well to inputs in agriculture (Horton 1987; Gumul et al. 2011). On average, the dry matter content of potato tuber is 20% and a large proportion (60–80%) of dry matter is composed of starches, making it a food rich in carbohydrates (Lutaladio and Castaidi 2009). Besides being a rich source of carbohydrates, potato also contains some health promoting compounds such as phenolic acids, ascorbic acid, and carotenoids (Ezekiel et al. 2013).

In Ethiopia, Potato is commonly consumed in the form of boiled and cooked meals in different traditional dishes or 'wot'. Recently, potato chips and French fries are flourished and found in hotels, restaurants, supermarkets, and small shops. Owing the maximum potato productivity potential, some processing companies like 'sun chips' are emerging and the demand for processing type potatoes are growing aside food security (Wassu 2016). Hence, the potato breeding program in the country should consider a selection of varieties not only for high yield but also for processing quality traits such as internal (specific gravity, dry matter, starch contents, reducing sugar) and external (tuber shape, eye depth, tuber fresh color and tuber skin color) traits of tubers (Gastelo et al. 2024; Seid et al. 2020). Knowledge of length, width, volume, surface area and center location of the mass, may be applied in the designing of sorting machinery, in predicting the surface needed when applying chemicals, shape factor (sphericity), and yield in the peeling operation (surface area) (Wright et al. 1986). The physical and chemical characteristics of the potato tubers vary from one variety to another (Kumar et al. 2004). Therefore, the choice of variety is probably the most critical decision concern aligning the tuber quality with the intended market preferences. In Ethiopia, more than 40 improved potato varieties have been released by different research institutions for high yielding, late blight resistance and wide adaptability. So far, the potato research program in the country however, devoted less on tuber quality traits and processing parameters except the few recently released varieties that considered tuber quality traits for processing. These few potato varieties with processing qualities not yet satisfied the ever-emerging processing industries for chips and French fries in the country. Hence, this study aimed to seek evaluating more potato genotypes that have merits for tuber quality traits used for processing and yield attributes.

Materials and methods

Planting materials, experimental site and design

The study consisted 24 potato genotypes of which 21 were selected from the germplasm pool introduced from the International Potato Centre (CIP) (i.e.; CIP396034.268, CIP393220.54, CIP395017.229, CIP392797.27, CIP395112.19, CIP399075.7, CIP393280.64, CIP398098.65, CIP393385.39, CIP396027.205, CIP393077.159, CIP399002.52, CIP394611.112, CIP392617.54, CIP381381.20, CIP398180.289, CIP398190.89, CIP398190.404, CIP391058.175, CIP396034.103, CIP391046.14) and 3 potato varieties released (i.e.; Belete, Gudanie and Dagim) in Ethiopia. Out of these, variety Gudanie was used as a check for this study since there was no any released potato varieties during the study. The experiment was carried out at Holetta Agricultural Research Centre experiment station during the main cropping season of 2017 with 9° 00′ N, 38° 29′ E, 2400 m. asl altitude and 1100 mm and 14.15 ℃ mean annual rainfall and temperature, respectively. The experiment was laid out in randomized complete block design (RCBD) with 3 replications and each plot was 3.6 m (length) × 4.5 m (width) (16.2 m^2 gross plot size) 6 rows each containing 12 plants and thus 72 plants per plot. The spacing between rows and plants was 0.75 m and 0.30 m, respectively. The spacing between plots and adjacent replications was 1 m and 1.5 m, respectively. The experimental field was prepared in accordance with the recommendations of Holetta Agricultural Research (Lemaga et al. 1992; MALR 2017).

Data collection

Yield and yield components

The data collected for yield variables include number of tubers per hill, average tuber weight (g/tuber) and tuber size distribution:—small (< 35 mm), medium (35 to 50 mm), and large (> 50 mm) as a percent of total harvested tubers (Ekin et al. 2009).

Total tuber yield (t ha^{-1}) It was determined as the sum of marketable and unmarketable tubers weight from the net plot area and converted to ton per hectare.

Marketable tuber yield (t ha^{-1}) This was determined from the weight of tubers obtained from the net plot after the sorting tubers and count number of tubers which are free from diseases, insect pests and greater than or equal to 35 mm and weighted tubers per hill that were converted to ton per hectare.

Unmarketable tuber yield (t ha^{-1}) The average weight of tubers that are diseased, insect attacked and small-sized (< 35 mm) were converted to ton per hectare.

External and internal tuber quality traits

Tuber geometric mean diameter (Dg) (mm): Tuber length (L), width (W) and thickness T) were used for measuring geometric mean diameter. Ten randomly selected potato tubers were taken from each plot using a digital caliper with an accuracy of 0.01 mm and the mean diameter was measured with L, W, and T. The geometric mean diameter (Dg) was computed using the cube root of the product of L, W, and T. $Dg = (LWT)^{0.333}$

Tuber length to width ratio (L/W = R) This was computed as the ratio of tuber length (L) to tuber width (W). R = L/W.

Sphericity of the tuber (Φ) (%) Tuber sphericity was determined based on suggestions given by Ahmadi et al. (2008). $\Phi = (Dg/\ L) \times 100$ where: Φ is sphericity of the tuber (mm^{-1}), Dg is geometric mean diameter (mm) and L is tuber length (mm).

Surface area (S) (mm^2) Tubers surface area was determined according to Baryeh (2000). $S = \pi\ Dg^2$ where: S is surface area (mm^2) and Dg is geometric mean diameter (mm).

Specific gravity of tubers (Sg) (gcm^{-3}) The specific gravity of tubers was determined using the air, underwater weight method. Five kilograms of fresh tubers as a composite sample from different shapes and sizes were randomly selected from each plot per genotype in a net bag and labeled. The tubers were washed with tap water and allowed to dry. Then weight in air followed by weight in water were taken. The specific gravity of each sample was determined according to the formula given by Gould (1995).

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Weight in air} - \text{Weight in water}}$$

Dry matter content (%) Tuber dry matter content (DMC) was calculated according to Porras et al. (2014). Five tubers of each variety were chopped (about 500 g total) into small 1–2 cm cubes. The cubers were mixed thoroughly and divided in to two sub-samples of 200 g each recording their fresh weight and allowed to dry. Subsequently, each sub-sample was placed in an oven dry set at 80 °C and dried for 48 h until constant weight. Each sub-sample was weighed immediately and recorded as dry weight. After getting the constant dry weight from each sample, the dry matter content for each sub-sample was then computed as one sample.

$$\text{Dry matter content}(\%) = \frac{\text{Dry weight}}{\text{Fresh weight}} * 100$$

Total starch content (g/100 g) The total starch content was estimated from dry matter percent. Starch content in percent was calculated according to AOAC (1980). Starch content (%) = 17.55 + 0.891 * (tuber dry weight% − 24.182).

Tuber eye depth This was described by a five levels numerical scores denoted from 1 to 5, where 1 = protruding, 2 = shallow, 3 = medium, 4 = deep, and 5 = very deep (Huaman et al. 1977).

Tuber skin color This was assessed visually at harvesting according to a color card (Huaman et al. 1977) on a 1–9 scale, where 1 = white-cream, 2 = yellow, 3 = orange, 4 = brown, 5 = pink, 6 = red, 7 = red-rose, 8 = purple and 9 = blackish.

Tuber flesh color This was evaluated visually using the color card (Huaman et al. 1977) on a code of 1–8, where 1 = white, 2 = cream, 3 = yellow-cream (bright), 4 = yellow, 5 = intense yellow, 6 = red, 7 = purple, 8 = violet.

Chips and french fries color Potato chips and French fry colors have an immense in processed and fried potato markets. Uniform sized (100–150 g) tubers were peeled and collected in cool tap water and sliced using a potato slice cutter and punched in tap water. The slices were blot- dried on paper towels to remove the free water. Before frying the potato slices, sunflower cooking oil was heated for 10 to 15 min until it reached 176 °C and ascertained with a thermometer. For each potato variety, 700 g of slices were fried 3 to 4 min at 176–180 °C using an electronic deep fat fryer until bubbling ceased (Amoros et al. 2000). The chips and French fry color was then determined using a standard color chart with a scale of 1 to 5 (1 = the lightest color-white to cream), 2 = light tan, 3 = dark tan, 4 = brown and 5 = dark brown. Chips and French fries colored between grade 1 and 2 is commercially acceptable (Amoros et al. 2000; CIP 2007).

Data analysis

The quantitative data was subjected to analysis of variance (ANOVA) using the SAS statistical software version 9.3 (SAS Institute 2010). Descriptive statistics was used to describe qualitative data. The comparison of the mean performance of genotypes was done with the significance of mean squares using Duncan's Multiple Range Test (DMRT).

Results

Mean performances of genotypes for yield components

Significant variation for yield component traits was observed among all genotypes (Table 1). The highest and significantly different mean values of average tuber number per hill were recorded from CIP393385.39 and average tuber weight in CIP392617.54. On the other hand, variety Dagim showed smallest average tuber number whereas CIP393385.39, CIP399002.52, and CIP396027.205 had lowest average tuber weight values. The reason for the mean value variation among genotypes in average tuber numbers may be due to inheritability of genotypes and the size of tubers. Tuber size distribution revealed the presence of significant differences among potato genotypes in this study (Table 1). Accordingly, genotypes CIP399002.52, CIP396027.205, and CIP399075.7 produced a significantly higher percentage of small-size tubers (< 35 mm). On the other hand, CIP395112.19 had a lower percentage of small-size (< 35 mm) tubers. The released potato variety Gudanie produced significantly more percent of medium size (35–50 mm) tubers, followed by CIP396034.103, CIP393220.54, CIP393385.39, CIP391046.14, CIP391058.175, Dagim, CIP381381.20 and CIP399075.7. However, 15 potato genotypes produced a lower percentage of medium-size (35–50 mm) tubers. Potato genotypes also showed a significant difference in the percent of large size (> 50 mm) tubers. Accordingly, CIP395112.19 produced the highest large size tuber proportion, followed by CIP392617.54 and CIP398190.89, while CIP399002.52 had a lower large size tubers distribution in proportion. The number of factors viz., inheritability of genotypes, plant growth rate, and size of seed tubers, the performance of sprout, emergence time as well as variety performance might have contributed to the observed variation in the number of small, medium, and large size tubers.

Table 1 Mean performance of 24 potato genotypes for yield components evaluated at Holetta in 2017

Genotype	Average tuber number per hill	Average tuber weight (g/tuber)	Tuber size distribution (%)		
			Small	Medium	Large
CIP396034.268	9.45^{ghi}	79.81^{a-d}	32.91^{def}	30.32^{f}	36.76^{bcd}
CIP393220.54	11.73^{c-g}	54.82^{hi}	32.48^{def}	48.95^{ab}	18.58^{h-k}
CIP395017.229	9.30^{ghi}	62.09^{fgh}	29.47^{d-h}	35.24^{def}	35.29^{cde}
CIP392797.27	8.62^{hi}	80.81^{a-d}	35.47^{cde}	36.71^{c-f}	27.81^{d-h}
CIP395112.19	9.31^{ghi}	85.76^{ab}	18.19^{h}	35.21^{def}	46.60^{a}
CIP399075.7	12.27^{cde}	47.71^{ij}	46.89^{abc}	42.13^{a-e}	10.98^{k}
CIP393280.64	10.67^{d-h}	69.53^{d-g}	34.29^{def}	36.80^{c-f}	28.91^{d-g}
CIP398098.65	13.76^{bc}	69.92^{def}	30.64^{d-g}	38.09^{c-f}	31.26^{c-f}
CIP393385.39	18.46^{a}	40.41^{j}	42.03^{bcd}	46.50^{abc}	11.47^{k}
CIP396027.205	12.06^{c-f}	41.21^{j}	48.32^{ab}	39.28^{b-f}	12.40^{jk}
CIP393077.159	12.54^{cd}	51.52^{hi}	39.11^{b-e}	39.05^{b-f}	21.85^{f-j}
CIP399002.52	15.06^{b}	40.75^{j}	56.67^{a}	34.38^{ef}	8.95^{k}
CIP394611.112	11.46^{c-g}	73.81^{cde}	37.39^{b-e}	36.13^{c-f}	26.48^{e-h}
CIP392617.54	9.72^{fgh}	89.11^{a}	19.44^{gh}	34.77^{def}	45.78^{ab}
CIP381381.20	10.82^{d-h}	67.31^{efg}	28.67^{e-h}	42.33^{a-e}	28.99^{d-g}
CIP398180.289	8.82^{hi}	82.43^{abc}	38.04^{b-e}	33.78^{ef}	28.19^{d-h}
CIP398190.89	10.29^{d-h}	80.43^{a-d}	27.96^{e-h}	32.72^{ef}	39.33^{abc}
CIP398190.404	10.69^{d-h}	79.73^{a-d}	22.56^{fgh}	40.67^{b-f}	36.77^{bcd}
CIP391058.175	10.94^{d-h}	61.29^{fgh}	37.40^{b-e}	43.66^{a-e}	18.95^{g-k}
CIP396034.103	9.86^{e-h}	71.49^{c-f}	22.04^{fgh}	51.59^{a}	26.38^{e-h}
CIP391046.14	9.43^{ghi}	58.61^{gh}	40.57^{b-e}	45.54^{a-d}	13.90^{ijk}
Belete	11.57^{c-g}	75.80^{b-e}	31.94^{def}	38.86^{b-f}	29.21^{def}
Gudaine	11.94^{c-f}	61.08^{fgh}	33.00^{def}	52.35^{a}	14.65^{ijk}
Dagim	7.18^{i}	67.13^{efg}	33.44^{def}	43.35^{a-e}	23.21^{f-i}
Range	7.18–18.46	40.41–89.11	18.19–56.67	30.32–52.35	8.95–46.6
Mean	11.08	66.36	34.12	39.93	25.95
CV (%)	11.34	8.89	18.96	13.79	20.41
P-value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Mean values with similar letter(s) in each column had not significant differences at $P < 0.05$

Mean performances of genotypes for tuber yield

The studied potato genotypes had showed a wide range of variation in total tuber yield that ranged from 21.48 to 42.68 t ha^{-1} with the mean performance of 31.63 t ha^{-1} (Table 2). The mean total tuber yield of released varieties (Belete, Gudanie, and Dagim) was in the range between 21.48 to 38.83 t ha^{-1}. The five advanced clones CIP398098.65, CIP392617.54, CIP398190.404, CIP394611.112 and CIP398190.89 gave total tuber yield higher than the mean tuber yield of the two released varieties, Gudanie and Dagim. However, low total tuber yield was obtained from Dagim. Marketable tuber yield ranged from 19.65 to 37.36 t ha^{-1} with a mean performance of 28.74 t ha^{-1}. The eight advanced clones had higher marketable tuber yield than the two released varieties Gudanie and Dagim. CIP398190.89, CIP398098.65, and CIP398180.289 advanced clones had higher unmarketable tuber yield than the varieties Gudanie, Belete and Dagim.

Table 2 Mean performance of 24 potato genotypes for tuber yield evaluated at Holetta in 2017

Genotype	Total tuber yield (t ha^{-1})	Marketable tuber yield (t ha^{-1})	Unmarketable tuber yield (t ha^{-1})
CIP396034.268	33.49$^{b–g}$	31.72$^{a–e}$	1.77^{ef}
CIP393220.54	28.47^{ghi}	25.56$^{e–j}$	2.91^{cde}
CIP395017.229	25.55^{hij}	23.36$^{g–j}$	2.19^{def}
CIP392797.27	30.92$^{e–h}$	28.52$^{c–h}$	2.41$^{c–f}$
CIP395112.19	35.42$^{b–f}$	32.12$^{a–e}$	3.30^{cd}
CIP399075.7	25.69^{hij}	23.54$^{f–j}$	2.16^{def}
CIP393280.64	33.03$^{b–g}$	31.39$^{a–e}$	1.63^{ef}
CIP398098.65	42.68^{a}	37.36^{a}	5.32^{a}
CIP393385.39	32.87$^{b–g}$	29.63$^{b–g}$	3.24^{cd}
CIP396027.205	21.91^{j}	19.65^{j}	2.27^{def}
CIP393077.159	28.60^{ghi}	26.20$^{d–i}$	2.41$^{c–f}$
CIP399002.52	27.27$^{g–j}$	23.58$^{f–j}$	3.69^{bc}
CIP394611.112	37.35$^{a–e}$	32.77$^{a–d}$	4.59^{ab}
CIP392617.54	38.27^{abc}	34.58^{abc}	3.70^{bc}
CIP381381.20	32.07$^{c–h}$	29.30$^{c–g}$	2.77$^{c–f}$
CIP398180.289	32.38$^{b–g}$	27.22$^{d–h}$	5.16^{a}
CIP398190.89	36.80$^{a–e}$	31.47$^{a–e}$	5.33^{a}
CIP398190.404	37.89$^{a–d}$	36.22^{ab}	1.67^{ef}
CIP391058.175	29.80$^{f–i}$	27.40$^{d–h}$	2.40$^{c–f}$
CIP396034.103	31.40$^{d–h}$	30.03$^{b–f}$	1.36^{f}
CIP391046.14	24.37^{ij}	22.65^{hij}	1.72^{ef}
Belete	38.83^{ab}	36.21^{ab}	2.61$^{c–f}$
Gudaine	32.53$^{b–g}$	29.34$^{c–g}$	3.19^{cd}
Dagim	21.48^{j}	19.89^{ij}	1.59^{ef}
Range	21.48–42.68	19.65–37.36	1.36–5.33
Mean	31.63	28.74	2.89
CV (%)	10.81	11.88	24.82
P-value	< 0.01	< 0.01	< 0.01

Mean values with similar letter(s) in each column had not significant differences at $P < 0.05$

Mean performances of genotypes for tuber external and internal quality traits

The highest and significantly different tuber external quality traits of geometric mean diameter and surface area was recorded from CIP395017.229, sphericity of the tuber from CIP396027.205 and CIP393385.39, length to width ratio from CIP399075.7 (Table 3). On the other hand, the released variety Dagim showed lowest geometric mean diameter and surface area, while the lowest sphericity of tuber value was recorded from CIP399075.7. Potato genotypes showed significant differences for internal quality traits (specific gravity, dry matter content and total starch content). The genotypes varied for specific gravity, dry matter content and total starch content which ranged from 1.070 to1.103 gcm^{-3}, 18.67 to 25.75% and 12.64% to 18.95%, respectively. The genotype CIP399002.52 had the highest specific gravity, dry matter content and total starch content. These differences might be related to genetic variations among potato genotypes. Furthermore, higher dry matter content in these genotypes, as starch and dry matter contents of potato are directly related to each other. Genotypes with high specific gravity showed higher percentage of dry matter content and total starch content. This suggested the importance of continuous evaluation of these breeding materials allowing breeders to identify and obtain genotypes with high tuber quality traits for future breeding programs. CIP395017.229 showed the lowest specific gravity, dry matter content and total starch content.

Qualitative traits of tubers

The highest proportion of genotypes had ovate and elliptic tuber shape (25%), shallow eye depth (50%), yellow tuber skin color (25%), white tuber flesh color (41.67%), dark tan chips color (37.5%) and white to cream French fries color (37.50%) (Fig. 1a–f). Small proportion of genotypes had compressed and obovate tuber shape (8.33%), deep and very deep eye depth (12.5%), red–purple and purple tuber skin color (4.17%), yellow cream tuber flesh color (8.33%), light tan and brown chips color (16.67%) and brown French fries color (4.17%). According to both tuber characteristics and processing qualities traits potato genotypes CIP398098.65, CIP392617.54, CIP398190.404, CIP394611.112, CIP398190.89 and Gudaine could be preferable for chips and French fries (Table 4).

Table 3 Mean performance of 24 potato genotypes for tuber physical quality related traits evaluated at Holetta in 2017

Genotype	Geometric mean diameter (mm^3)	Surface area (mm^2)	Sphericity of tubers (%)	Length to width ratio	Specific gravity (gcm^{-3})	Dry matter content (%)	Total starch content (g/100 g)
CIP396034.268	57.61$^{a–d}$	10449$^{a–e}$	80.84^{dec}	1.20^{fgh}	1.089$^{c–g}$	22.75$^{c–h}$	16.27$^{c–h}$
CIP393220.54	51.90^{def}	8641$^{c–g}$	77.29^{f}	1.35^{cde}	1.082$^{e–i}$	21.17$^{f–j}$	14.86$^{f–j}$
CIP395017.229	61.15^{a}	11753^{a}	82.93^{cde}	1.19$^{f–i}$	1.070^{j}	18.67^{k}	12.64^{k}
CIP392797.27	59.20^{abc}	11008^{abc}	77.60^{f}	1.35^{cde}	1.073^{ij}	19.17^{jk}	13.08^{jk}
CIP395112.19	58.25$^{a–d}$	10677$^{a–e}$	88.82^{b}	1.06^{ij}	1.081$^{f–i}$	20.83$^{g–k}$	14.57$^{g–k}$
CIP399075.7	57.21$^{a–e}$	10287$^{a–f}$	61.98^{h}	1.87^{a}	1.078^{hij}	20.25^{ijk}	14.05^{ijk}
CIP393280.64	54.72$^{a–f}$	9425$^{a–g}$	86.63^{cb}	1.07^{hij}	1.094$^{a–d}$	23.83$^{a–e}$	17.24$^{a–e}$
CIP398098.65	58.41$^{a–d}$	10717$^{a–e}$	78.41^{def}	1.33^{def}	1.098^{abc}	24.75^{abc}	18.06^{abc}
CIP393385.39	51.78^{def}	8434^{efg}	94.16^{a}	1.01^{j}	1.079$^{g–j}$	20.50^{hk}	14.27$^{h–k}$
CIP396027.205	51.49^{def}	8328^{efg}	94.27^{a}	1.00^{j}	1.072^{ij}	19.08^{jk}	13.01^{jk}
CIP393077.159	52.77$^{b–f}$	8746$^{b–g}$	88.08^{b}	1.09^{hij}	1.082$^{e–i}$	21.25$^{f–j}$	14.94$^{f–j}$
CIP399002.52	50.24^{ef}	7933^{fg}	83.33^{cd}	1.20^{fgh}	1.103^{a}	25.75^{a}	18.95^{a}
CIP394611.112	59.32^{abc}	11065^{abc}	77.50^{f}	1.34^{de}	1.100^{ab}	25.17^{ab}	18.43^{ab}
CIP392617.54	59.10^{abc}	10992$^{a–d}$	77.95^{ef}	1.30^{efg}	1.083$^{e–i}$	21.25$^{f–j}$	14.94$^{f–j}$
CIP381381.20	56.39$^{a–f}$	10005$^{a–g}$	82.25^{cf}	1.20^{fgh}	1.086$^{d–h}$	22.08$^{e–i}$	15.68$^{e–i}$
CIP398180.289	54.35$^{a–f}$	9373$^{a–g}$	82.76^{cde}	1.17^{ghi}	1.091$^{b–e}$	23.25$^{b–f}$	16.72$^{b–f}$
CIP398190.89	59.35^{abc}	11094^{abc}	70.62^{g}	1.47^{bc}	1.085$^{d–h}$	21.75$^{e–i}$	15.38$^{e–i}$
CIP398190.404	59.28^{abc}	11093^{abc}	78.15^{ef}	1.28^{efg}	1.091$^{b–f}$	23.08$^{b–g}$	16.57$^{b–g}$
CIP391058.175	53.04$^{b–f}$	8886$^{b–g}$	72.54^{g}	1.46^{bcd}	1.084$^{d–h}$	21.67$^{e–i}$	15.31$^{e–i}$
CIP396034.103	52.91$^{b–f}$	8794$^{b–g}$	89.11^{b}	1.02^{j}	1.097^{abc}	24.33$^{a–d}$	17.68$^{a–d}$
CIP391046.14	52.16$^{c–f}$	8544$^{d–g}$	70.90^{g}	1.54^{b}	1.081$^{f–i}$	20.92$^{g–j}$	14.64$^{g–j}$
Belete	59.73^{ab}	11219^{ab}	77.07^{f}	1.31^{ef}	1.088$^{c–h}$	22.50$^{d–i}$	16.05$^{d–i}$
Gudaine	54.70$^{a–f}$	9413$^{a–g}$	70.92^{g}	1.53^{b}	1.085$^{d–h}$	21.75$^{e–i}$	15.38$^{e–i}$
Dagim	49.42^{f}	7669^{g}	80.72^{def}	1.25^{efg}	1.080$^{g–j}$	20.75$^{h–k}$	14.49$^{h–k}$
Range	49.42–61.15	7669–11,753	61.98–94.27	1.00–1.87	1.070–1.103	18.67–25.75	12.64–18.95
Mean	55.60	9772.71	80.20	1.27	1.09	21.94	15.55
CV (%)	6.50	12.75	3.35	5.64	0.50	5.37	6.76
P-value	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Mean values with similar letter(s) in each column had not significant differences at P < 0.05

Discussions

The observed highly significant ($p \leq 0.01$) variation in quality and tuber yield traits among the 24 potato genotypes is presented in Table 1. Insights obtained from this study provide a good opportunity for potato breeders to select genotypes with better processing quality to be used either for developing variety or genotypes that can be used as future parental lines for the targeted traits. In similar studies, Lemma et al. (2020); Addisu et al. (2013), Wassu (2014), Misgana et al. (2015), Getachew et al. (2016), Tesfaye et al. (2012a), Wassu (2016), Wassu (2017), Habtamu et al. (2016) reported significant variability among potato genotypes for agronomic traits, yield components, tuber size distribution, tuber yield, internal and external tuber processing quality traits under different environment conditions.

The five advanced clones CIP398098.65, CIP392617.54, CIP398190.404, CIP394611.112, and CIP398190.89 were selected for their high total tuber yields over 36.80 t/ha, with more than 31.47 t/ha marketable tuber yield, greeter than 69.92 g/tuber average tuber weight, higher than 58.41 mm^3 geometric mean diameter, more than 21.25% dry matter content and excellent quality for chips and French fries processing (Tables 1, 2, 3, 4).. Likewise, Getachew et al. (2016) reported 3.8 to 114.5 g, 0.06–43.7 t ha^{-1} and 0.8–46.1 t ha^{-1} of average tuber weight, marketable tuber yield and total tuber yield, respectively, for 24 potato genotypes evaluated in Bale highlands, South Eastern Ethiopia. Addisu et al. (2013) reported tuber size distribution variability from 4.6 to 56.67% for small size tubers, 27.80 to 49.00% for medium size tubers and 0.5 to 65.7% for large size tubers. The difference in tuber number might be due to varietal character, affected by better performance of the variety (Kumar et al. 2007). The effect of heredity was significant with regard to tuber sizes (Muthuraj et al. 2005). Vegetative growth and stem

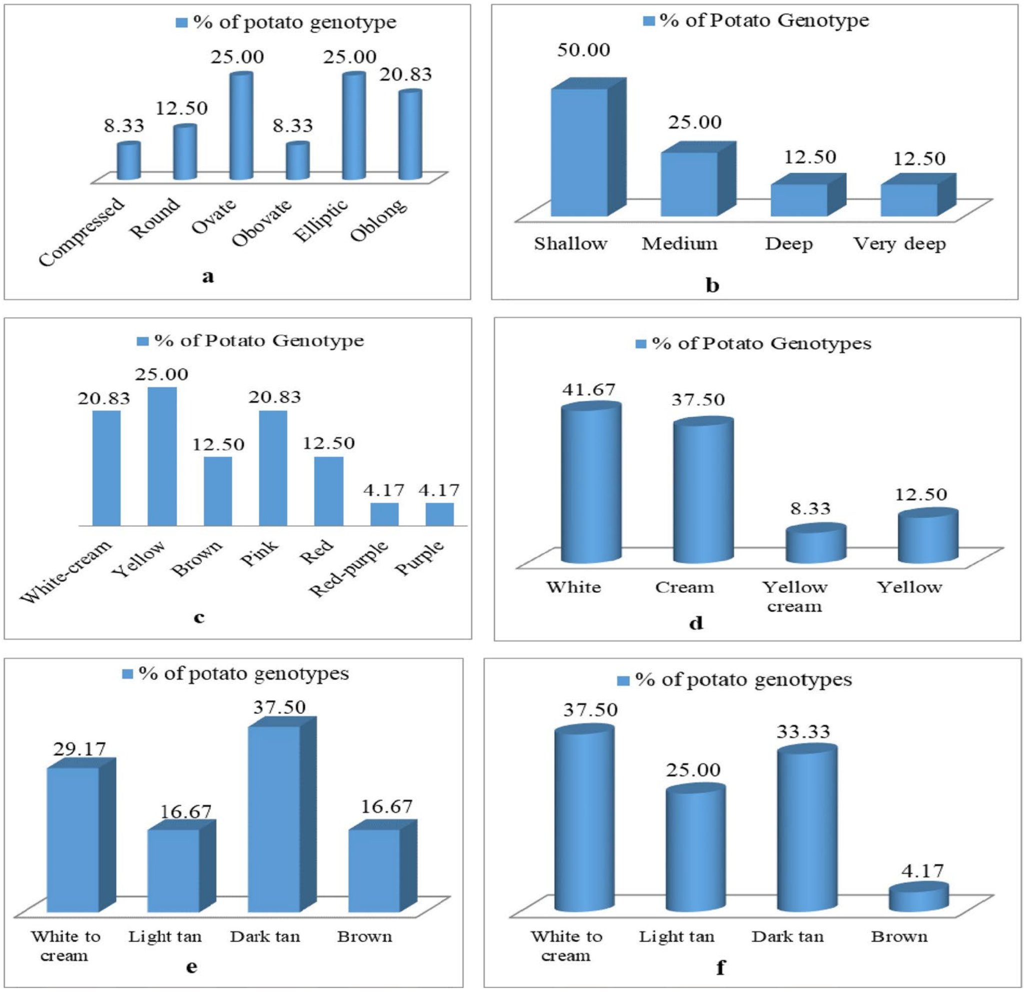

Fig. 1 Distribution of 24 potato genotypes into different categories of qualitative traits **a** tuber shape, **b** tuber eye depth, **c** tuber skin color, **d** tuber flesh color, **e** chips color and **f** French fries color

numbers are essential factors that affect the percentage of different tuber sizes (Singh et al. 1997). More number of under size tubers may be due to the higher vigor of plants combined with delayed maturity (Sharma and Singh 2009). Moreover, a higher proportion of large-size tubers may be due to rapid plant emergence and better plant growth (Patel et al. 2008). Kumar and Ezekiel (2006); and Patel et al. (2008) described that rapid plant emergence and better plant growth results in higher number of medium size tubers. Sufficient growth (stem number and plant height) had positive contribution to tuber number.

Habtamu et al. (2016) reported 46.08 mm^3 to 74.74 mm^3 for geometric mean diameter, 69.19% to 92.00% for sphericity of tubers, 6698.79 mm^2 to 17,805.70 mm^2 for surface area of tubers under Haramaya, Arberkete and Hirna environments. Wassu (2017) observed varieties at three locations namely, Haramaya, Hirna and Arberkete and the tuber specific gravity, dry matter content and starch content ranged from 1.065 to 1.097 gcm^{-3}, 19.49 to 26.98% and 10.71 to 16.88%, respectively. Aggarwal et al. (2017) reported that tuber internal quality ranged from 1.055 to 1.095 for specific gravity, 16.0–24.0% for dry matter content and 12.25–15.20% for total starch content. Abbas et al. (2011) evaluated 32 potato genotypes in Pakistan and the genotypes had 1.03–1.14 g/cm^3 for specific gravity, 14.86–25.65% for dry matter content and 9.00–20.01% of total starch content. Tesfaye et al. (2012b) evaluated 25 released potato varieties and the varieties overall values ranged from 17.65 to 26.70% dry matter content and 9.75 to 17.82% for total starch content under Adet, Merawi and Debretabor environments.

Abbas et al. (2012) observed 59.38% white tuber skin color, 81.25% oval tuber shape, 71.88% shallow eye depth and 65.63% cream flesh color among 32 potato genotypes suggesting oval shape tubers and shallow to medium eyes

Table 4 Results of tuber characteristics and processing qualities of 24 tested potato genotypes at Holetta in 2017

Genotype	Tuber shape	Eye depth	Tuber skin color	Tuber flesh color	Chips color	French fries color
CIP396034.268	Ovate	Deep	Pink	Cream	Dark tan	Dark tan
CIP393220.54	Ovate	Medium	Yellow	Cream	Dark tan	Dark tan
CIP395017.229	Obovate	Shallow	Yellow	Cream	Light tan	Light tan
CIP392797.27	Elliptic	Shallow	Brown	Cream	Dark tan	Dark tan
CIP395112.19	Compressed	Shallow	Brown	White	Dark tan	Light tan
CIP399075.7	Elliptic	Shallow	Pink	Yellow	White-cream	White-cream
CIP393280.64	Oblong	Deep	Pink	White	White-cream	White-cream
CIP398098.65	Ovate	Medium	Purple	Yellow-cream	Light tan	White-cream
CIP393385.39	Round	Very Deep	Red	White	Dark tan	Dark tan
CIP396027.205	Round	Very Deep	Red	White	Brown	Brown
CIP393077.159	Compressed	Deep	Pink	Cream	Dark tan	Dark tan
CIP399002.52	Ovate	Shallow	Pink	White	Brown	Light tan
CIP394611.112	Oblong	Medium	Red–Purple	Cream	White-cream	White-cream
CIP392617.54	Obovate	Shallow	White-Cream	White	Light tan	White-cream
CIP381381.20	Oblong	Medium	Brown	White	Brown	Light tan
CIP398180.289	Oblong	Medium	White-Cream	Cream	Brown	Light tan
CIP398190.89	Elliptic	Shallow	White-Cream	Yellow-cream	White-cream	Light tan
CIP398190.404	Ovate	Shallow	White-Cream	White	Light tan	White-cream
CIP391058.175	Elliptic	Shallow	Yellow	Cream	Dark tan	Dark tan
CIP396034.103	Round	Very Deep	Red	Cream	White-cream	White-cream
CIP391046.14	Elliptic	Shallow	Yellow	Yellow	Dark tan	Dark tan
Belete	Oblong	Medium	Yellow	White	Dark tan	Dark tan
Gudaine	Elliptic	Shallow	White-Cream	White	White-cream	White-cream
Dagim	Ovate	Shallow	Yellow	Yellow	White-cream	White-cream

depth are preferred types for making chips and French fries. The study by Marwaha et al. (2010) also suggested potato tubers with uniform in size, round to oval in shape having a diameter of 45–80 mm would be preferable for processing purposes. For French fries, oblong to long tubers > 75 mm in length is preferred. Pandey et al. (2000) reported characters such as tuber appearance, size, shape, color and skin finish, which influence consumer choice are considered useful quality attributes in potatoes. Latifeh and Davoud (2014) evaluated 127 hybrids with their parent potato genotypes based on agronomic quantitative traits and selected 24 hybrids based on the criteria of tuber skin and flesh of yellow to light yellow color, shallow eye depth, and uniform tuber indicating potato qualitative traits could be used as important selection criteria for variety development.

Conclusion

In conclusion, this study revealed the existence of significant difference among potato genotypes in their tuber yield, yield components, external and internal quality related traits. This will provide good opportunity for breeders to select genotypes with better tuber yield performance and traits that possess processing quality. Finally, according to both external and processing quality traits potato genotypes CIP398098.65, CIP392617.54, CIP398190.404, CIP394611.112, and CIP398190.89 and Gudaine could be preferable for chips and French fries. The genotypes that had either shallow or medium eye depth could be acceptable for processing quality traits. Potato genotypes with desirable yield and processing quality traits could also be used as parents for future crossing programs in Ethiopia.

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Author contributions

Ebrahim Seid designed and conceptualization the research. Ebrahim Seid and Lemma Tessema conducted the data analysis, wrote and edited the manuscript.

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Data availability

All data are available in the manuscript.

Declarations

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Not applicable.

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