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Performance Evaluation of Advanced Potato (*Solanum tuberosum* L) Genotypes for Yield and Quality Traits in Bekoji, Southeastern Ethiopia

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Abstract:- In Ethiopia, the potato serves as a vital source of food security and income for millions of smallholder farmers. Earlier research efforts concerning variety development concentrated on tuber yield and resistance to late blight with broad adaptability. Up to now, the potato research program in the country has focused less on tuber quality traits and processing characteristics, with the exception of a few recently released varieties that have taken tuber quality traits for processing into account. These limited potato varieties with processing attributes have not yet met the growing demands of the processing industries in the country. Therefore, this research sought to assess additional potato genotypes that possess advantages for tuber quality characteristics relevant to processing and yield traits. The study was structured as a randomized complete block design with three repetitions, utilizing fifteen potato genotypes to assess the processing quality characteristics of advanced potato genotypes at the Bekoji substation of the Kulumsa Agricultural Research Centre during the main cropping season of 2022 and 2023. 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 genotypes varied for dry matter content, specific gravity, and total starch content which ranged from 18.32% to 23.66%, 1.07 to 1.097 g/cm³, 18.67 to 25.75%, and 12.03% to 17.08%, respectively. The genotype CIP315009.71 had the highest specific gravity, dry matter content, and total starch content. The four advanced clones CIP315003.132, CIP315008.160, CIP315009.71, and CIP315004.61 produced a total tuber yield that exceeded the average tuber yield of the released variety, Burka. This research suggests that selecting potato genotypes based on both external and internal tuber quality characteristics would accelerate the development of diverse potato varieties with processing attributes in the country, taking into account a thorough study that includes a broader range of potato genotypes across various growing conditions.

Keywords Tuber quality, Processing quality traits, Potato genotypes

1. Introduction

Potato (*Solanum tuberosum* L.) is the fourth most-produced crop globally, with approximately 383 million tons harvested from 16.8 million hectares annually [1]. Potato is grown in more than 150 countries under temperate, subtropical, and tropical conditions and represents a staple food for approximately one billion people in the world, about half of whom live in developing countries [2]. Global statistics also indicate that potato production has significantly increased in developing

countries such as Africa, reaching 26 million metric tons [3]. In Africa, potato production and harvested areas have more than doubled over the last two decades [3].

Primarily cultivated for human consumption, potato is a vital source of energy and nutrition, providing high levels of carbohydrates, quality proteins, essential minerals, and antioxidants [4-6]. It reaffirms the increasing importance of potatoes as a source of food, employment, and income in Asia, Africa, and Latin America [7]. Potato provides significant amounts of nutritional value to the human diet for the rural and urban poor who have few food options rich in protein, vitamins, macro- and micronutrients, polyphenols, carotenoids, and tocopherols [7]. Thus, nutritionally, it can be considered a well-balanced food crop with a good ratio between protein and calories and can be regarded as a good weaning food [8-9]. Potato is a nutritionally balanced food that provides a high calorie intake and a substantial number of vitamins. It is rich in protein, calcium, potassium, and vitamins, and has an especially good amino acid balance [10]. The economic contribution of the crop in terms of employment, income generation, export earnings, and ultimately to the national income is significant [11].

Potato (*Solanum tuberosum* L.) is a vital crop for food security and income generation among smallholder farmers in Ethiopia, particularly in highland regions where agroecological conditions support its cultivation [12-14]. Over the past decade, Ethiopia's potato cultivation area has expanded significantly, from 200,000 ha in 2013 to 300,000 ha in 2023, reflecting its increasing role in the agricultural economy [15]. In Ethiopia, potato ranks at the top 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% of this produce is utilized for household food purposes, while nearly 20% is marketed as an income source [16]. 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 have flourished and are found in hotels, restaurants, supermarkets, and small shops. Owing to the maximum potato productivity potential, some processing companies like 'Sun Chips' are emerging, and the demand for processing-type potatoes is growing alongside food security [17]. In Ethiopia, potato is largely grown for fresh consumption, although its use in processing fried products is increasing recently. It is commonly consumed in the form of boiled and cooked meals in different traditional dishes or 'wot.' Recently, consuming potato chips, crisps, and roasted potatoes has become common

practice, especially in cities like Addis Ababa, Hawassa, Adama, Mekele, and Dire Dawa. In urban areas, it is also usually consumed mixed with other vegetables as a salad [18].

There are distinct expectations on the part of consumers for certain types of potatoes to have specific cooking and processing qualities. Therefore, before selecting a variety for processing, such as chips, growers should consider the market potential and quality characteristics, as well as the ability to produce potatoes with a high specific gravity [19]. As the potato processing industry emerges as a fast-growing sector in different countries, potatoes must fulfill certain quality attributes, such as low reducing sugar and high dry matter (DM) content [20]. The physical and chemical properties of potato tubers differ among various varieties. Consequently, selecting the variety is likely the most crucial decision related to matching tuber quality with the desired market preferences. In Ethiopia, over 40 new potato varieties have been released by various research organizations for high yield, resistance to late blight, and broad adaptability. Until now, the potato research initiative in the country has focused less on tuber quality characteristics and processing parameters, apart from a few recently introduced varieties that have taken tuber quality traits for processing into account. These limited potato varieties with processing attributes have yet to meet the growing demands of the processing industries for chips and French fries in the nation. Thus, this study aims to assess additional potato genotypes that possess advantages for tuber quality characteristics relevant to processing and yield attributes. Therefore, this study was conducted with the objectives of evaluating and selecting suitable potato genotypes with higher tuber yield, especially targeting better processing qualities.

2. Materials and Methods

2.1. Description of the Study Area for Field Experiment

The field experiment was conducted at the Bekoji testing location during the 2022 and 2023 main cropping seasons (June-November). Bekoji is the major potato-growing area in the Arsi zone of the Oromia region, which is about 237 km from Addis Ababa. The soil composition in the study area is primarily clay, which is acidic in nature, a characteristic that can influence plant growth and pest behavior. The agro-climatic conditions in this region are classified as wet, with an average annual rainfall of 1,020 mm. Detailed information about the testing site is described in Table 1.

Table 1: Geographical coordinates and soil type of testing location.

Location	Latitude	Longitude	Altitude	Mean annual rainfall	Temperature		Soil type
					Min	Max	
Bekoji	07°32'37"N	39°15'21"E	2780	1020	7.9	18.6	clay

Source: Kulumsa Agricultural Research Center; Bekoji Meteorology sub-station, 2022 & 2023.

Table 2. Mean temperature, rainfall, and relative humidity of two seasons at Bekoji experimental site.

Cropping season	Cropping months	Mean monthly rainfall (mm)	Mean of air Temperature (%)		Relative Humidity (%)
			Minimum	Maximum	
2022	May	82.9	6.5	20.8	58
	June	157.2	4.1	20.4	73
	July	298.3	4.2	18.9	84
	August	192.9	4.2	18.9	83
	September	110.0	4.5	19.1	78
	October	88.2	2.8	20.5	69
2023	May	75.2	3.7	21.8	75
	June	83.6	3.6	23.6	79
	July	214.0	3.4	23.5	84
	August	195.3	3.7	20.9	86
	September	101.1	3.8	19.7	79
	October	58.5	3.5	20.7	80

Source: Kulumsa Agricultural Research Center; Bekoji Meteorology station, 2022 & 2023

2.1.2 Field experimentation, Experimental design and crop husbandry

Fifteen advanced potato genotypes, including one standard check (Burka), were evaluated. Detailed information about the experimental materials was described in Table 3 below.

Table 3: List of evaluated potato experimental materials (genotypes)

No.	Treatments	Status	No.	Treatments	Status
1	CIP315003.25	Advanced clone	9	CIP315004.61	Advanced clone
2	CIP315009.70	Advanced clone	10	CIP315003.83	Advanced clone
3	CIP315003.132	Advanced clone	11	CIP315003.166	Advanced clone
4	CIP315008.182	Advanced clone	12	CIP315010.161	Advanced clone
5	CIP315008.160	Advanced clone	13	Burka	Registered variety
6	CIP315008.154	Advanced clone	14	CIP315004.13	Advanced clone
7	CIP315004.113	Advanced clone	15	CIP315009.30	Advanced clone
8	CIP315009.71	Advanced clone			

Genotypes Sources: - Holeta Agricultural Research Center

2.1.3 The Experimental Designs and Field Trial Management

The trial was conducted using a randomized complete block design with three replications to evaluate the selected fifteen genotypes along with standard checks (Table 2). Medium-sized (35-45 mm diameter) and vigorous sprouted potato tubers were planted in the first week of June at a spacing of 75 cm between rows and 30 cm between plants, respectively, in a gross plot size of 9 m² (3 m x 3 m), which accommodates 40 plants. Agronomic practices were performed at the appropriate times to facilitate root, stolon, and tuber growth for the crop. To prevent late blight disease, a fungicide (Redomil Gold MZ 68 WG) was sprayed once during the cropping season. Two weeks before harvesting, as the crop attained maturity (yellowing of stems and senescence of leaves), de-hilling was done to thicken the tubers.

2.1.4 Data Collected

2.1.4.1 Data collected on a plot basis:

Days to First Emergence (days): The number of days from the date of planting to the day when the first flower bud opens in a plot.

Days to 50% Flowering (days): The number of days from the date of planting to when about 50% of the plants produced flowers.

Days to Maturity (days): The number of days from the date of planting to maturity. Data collected on the plant:

Number of Main Stems / Hills : 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.

Plant Height (cm): The plant height was measured from five samples using a measuring tape from ground level to the tip of the plant, expressed in centimeters, and the mean was computed.

Average Tuber Weight (g): This was determined by dividing the total fresh tuber yield by their respective total tuber number.

Late Blight : Disease records commenced on 22 August 2022 and 2023, which was 46 days post-planting, right after disease symptoms manifested in susceptible genotypes. The evaluation was conducted every 7 days until most of the genotypes reached physiological maturity. The occurrence and severity of the disease were evaluated according to the CIP [21] guidelines. The Area Under the Disease Progress Curve (AUDPC) was also calculated from disease severity recorded at various set date intervals.

Table 4. Field key for assessing potato late blight

CIP Scale value	Blight (%)		Symptoms
	Mean	Limits	
1	0		No late blight observable.
2	2.5	Traces- < 5	Late blight present. Maximum 10 lesions per plant.
3	10	5-< 15	Plants look healthy, but lesions are easily seen at closer distance. Maximum foliage area affected by lesions or destroyed corresponds to no more than 20 leaflets.
4	25	15 - < 35	Late blight easily seen on most plants. About 25% foliage is covered with lesions or destroyed.
5	50	35 - < 65	Plots look green; however, all plants are affected. Lower leaves are dead. About half the foliage area destroyed.
6	75	65 - < 85	Plots look green with brown flecks. About 75% of each plant is affected. Leaves of the lower half of plants are destroyed.

7	90	85 - < 95	Plots neither predominantly green nor brown. Only top leaves are green. Many stems have large lesions.
8	97.5	95 - < 100	Plot is brown-colored. A few top leaves still have some green areas. Most stems have lesions or are dead.
9	100		All leaves and stems dead.

2.1.4.2 Area under the disease progress curve (AUDPC)

Area under the disease progress curve is used to combine multiple disease severity into single value. The area under the disease progress curve was obtained by following formula [22]:

$$\text{AUDPC} = \sum_{i=1}^{n-1} (Y_i + 1 + Y_{i+1}) / 2 (T_{i+1} - T_i) \quad \text{where, } Y_i = \text{severity \% on the } i^{\text{th}} \text{ date}$$

T_i = date on which disease was scored n = total number of dates on which disease was scored

2.1.4.3 Yield and Yield Components

Total tuber yield (t ha⁻¹): - It was determined as the sum of marketable and unmarketable tuber weights from the net plot area and converted to tons per hectare.

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

Unmarketable tuber yield (t ha⁻¹): - The average weight of tubers that are diseased, insect-attacked, and small-sized (< 35 mm) was converted to tons per hectare.

Bulking rate (g day⁻¹): Was calculated as the total weight of tubers harvested from the net plot divided by the number of days taken from the date of 50% flowering to physiological maturity [23].

2.1.4.4 External and Internal Tuber Quality Traits

Specific gravity of tubers (Sg) (g cm⁻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, the weight in air followed

by the weight in water was taken. The specific gravity of each sample was determined according to the formula given by Gould [24].

$$\text{Specific gravity} = \frac{\text{weight of potato tubers in air}}{\text{weight of potato tubers in air} - \text{weight of potato tuber in water}}$$

Dry matter content (%) Tuber dry matter content (DMC) was calculated according to [25]. Five tubers of each variety were chopped (about 500 g total) into small 1–2 cm cubes. The tubers 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.

$$\text{Dry matter} = \frac{\text{dry weight}}{\text{fresh weigh}} * 100$$

Total starch content (g/100 g):- The total starch content was estimated from dry matter percent. Starch content in percent was calculated according to [26].

$$\text{Starch content (\%)} = 17.55 + 0.891 * (\text{tuber dry weight\%} - 24.182).$$

Tuber shape: Was determined according to [27] who described eight types of tuber shape, which will be transformed into numerical scores from 1 to 8, where 1 = compressed, 2= round, 3=ovate, 4=obovate, 5= elliptic, 6=oblong, 7=long-oblong and 8=elongate.

Tuber Eye depth: Was determined according to [28], who described nine types of tuber eye depth, which will be transformed into numerical scores from 1 to 9, where 1 = Very deep, 2 = Very deep to deep, 3 = Deep, 4 = Deep to medium, 5 = Medium, 6 = Medium to shallow, 7 = Shallow, 8 = Shallow to very shallow, 9 = Very shallow.

Tuber Appearance (Tuber Appearance): Was determined according to [29].

Scale	Scale	Description
1	Very poor	Very low yield, totally misshapes and non-uniform
3	poor	Low yield, some misshapes but non uniform size
5	Regular	Medium yield, good shape but non uniform size
7	Good	Good yield, good shape and uniform size
9	Very good	High yield, good shape and very uniform

Tuber uniformity: Overall assessment of tuber uniformity is based on the inspection of the harvested tubers using a 1 to 9 scale and determined according to [29].

Scale	Scale	Description
1	Very heterogeneous	All tuber sizes are present (from very small to large)
3	Heterogeneous	All tuber sizes are present but there is a predominant size
5	Intermediate	There are only 2 or 3 tuber sizes with a predominant size
7	Uniform	Only two sizes are present with a predominant tuber size
9	Very uniform	Only one tuber size

2.2 Statistical Analysis

2.2.1 Analysis of Variance

The `lm` function from the `stats` package in R software [30] was employed to analyze the data collected for each trait through analysis of variance (ANOVA), following the methodology described by Gomez and Gomez [31]. The assumptions of ANOVA for every data point were made prior to the analysis, and a combined data analysis across years was performed for all traits. A least significant difference was employed to analyze the mean performance of potato genotypes at a significance level of 5%.

2.2.2 Pearson Correlation Analysis

The graphical outputs of the Pearson correlation matrix were generated using `ggcorplot` from the `ggplot2` package of R software [30].

3 Results and Discussion

3.1 Analysis of Variance

The data obtained were subjected to ANOVA, and for the multiple comparisons of the mean performance of genotypes, the Least Significant Difference (LSD) test was used at the 5% threshold with R software version 4.6.0 [32]. A homogeneity test was conducted since the experiment spanned multiple seasons, necessitating analysis with combined ANOVA.

Homogeneity of error variances ensured that the data from both seasons were homogeneous ; thus, the data analysis was conducted using a combined analysis over the years.

3.2 Mean performances of genotypes for varieties for phenology and growth traits

From the results, analysis of variance (ANOVA) revealed that there were highly significant ($p \leq 0.01$) differences in agronomic, quality, and tuber yield traits among the 15 potato genotypes, except for days to fifty percent (50%) emergence (Table 5, 6 and 7). Days to 50% flowering, days to 50% maturity, plant height, and average stem number varied from 67.33 to 74.00 (days), 108.50 to 120.83 (days), 68.83 to 103.03 (cm), and 3.53 to 7.5 per plant, respectively (Table 1). Among the studied genotypes, CIP315009.30 exhibited earlier flowering than other genotypes, while CIP315003.132 was late to flower. Genotype CIP315009.70 showed earlier maturity than other genotypes, while CIP315004.113 was late to mature. The highest plant height was obtained from variety CIP315003.25 (103.03 cm), followed by CIP315008.154 (91.00 cm) and CIP315008.160 (88.83 cm), while the lowest plant height was observed for CIP315003.83 (66.93 cm). Relatively, the highest average stem number was observed from genotype CIP315008.154 (7.5). On the other hand, the lowest average stem number was counted from genotype CIP315004.113 (3.53). Moreover, the remaining genotypes were statistically similar. Plant height and average stem number varied from 61.48 to 74.87 (cm) and 3.70 to 5.57 (Table 5). Plant genetics, the quality of the plant material, and the cultivars' reactions to their growing conditions could all be contributing factors to these variations in plant height [33]. The results align with the findings of [45-39]. According to [40], significant variability was reported among potato genotypes for agronomic traits. According to [41], maturity durations ranged from 103 to 113.33 days, while [42] reported ranges between 86 and 106 days, showing the impact of genetic diversity, planting date, climate, and agronomic practices. [43] reported that Gudanie had the tallest plants (74.87 cm), followed by Belete (72.86 cm) and CIP-396034.103 (72.40 cm), while CIP-391046.14 was the shortest (61.48 cm).

Table 5: - Mean performance of 15 potato genotypes for phenology and growth traits evaluated at Bekoji in 2022 and 2023

S/No	Genotypes	Days to emergence	Days to 50% flowering	Days to maturity	Plant height	Average stem number
1	CIP315004.61	15.33	71.17 ^{c-f}	120.00 ^{ab}	85.83 ^{b-e}	3.93 ^{ef}
2	CIP315009.30	15.00	67.33 ^h	117.00 ^{a-c}	81.50 ^{b-f}	4.8 ^{b-e}
3	CIP315010.161	14.67	73.67 ^{a-c}	116.00 ^{a-c}	72.33 ^{fg}	5.93 ^b
4	CIP315003.132	14.5	74.00 ^a	118.67 ^{ab}	82.33 ^{b-f}	5.43 ^{bc}
5	CIP315004.113	14.33	71.33 ^{b-f}	120.83 ^a	80.00 ^{c-f}	3.53 ^f
6	CIP315008.160	14.33	68.50 ^{gh}	115.50 ^{a-c}	88.83 ^{bc}	5.37 ^{bc}
7	CIP315003.83	14.17	68.83 ^{f-h}	111.30 ^{a-c}	66.93 ^g	4.5 ^{c-f}
8	CIP315003.166	14.00	69.17 ^{e-h}	113.30 ^{a-c}	68.83 ^g	4.17 ^{d-f}
9	CIP315003.25	14.00	71.67 ^{a-e}	118.50 ^{a-c}	103.03 ^a	5.23 ^{b-d}
10	CIP315009.71	14.00	73.83 ^{ab}	118.50 ^{a-c}	77.00 ^{d-g}	4.77 ^{b-e}
11	CIP315009.70	13.83	73.17 ^{a-c}	108.50 ^c	79.63 ^{c-f}	4.87 ^{b-e}
12	CIP315008.182	13.67	70.17 ^{d-g}	114.67 ^{a-c}	86.33 ^{b-d}	5.90 ^b
13	CIP315004.13	13.50	71.17 ^{c-f}	116.67 ^{a-c}	76.00 ^{c-g}	4.13 ^{d^{ef}}
14	Burka	13.33	72.67 ^{a-d}	110.67 ^{bc}	76.60 ^{d-g}	5.80 ^b
15	CIP315008.154	13.33	71.17 ^{c-f}	114.67 ^{a-c}	91.00 ^b	7.50 ^a
Mean		14.13	71.19	115.66	81.08	5.06
CV (%)		13.62	3.15	7.52	10.91	20.38
P-value		ns	< 0.001	< 0.001	< 0.001	< 0.001

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

3.3 Mean performances of genotypes for tuber internal quality traits

Studied potato genotypes showed significant differences for internal quality traits (specific gravity, dry matter content, and total starch content). The genotypes varied for dry matter content, specific gravity, and total starch content, which ranged from 18.32% to 23.66%, 1.07 to 1.097 g/cm³, 18.67 to 25.75%, and 12.03% to 17.08%, respectively (Table 6). The genotype CIP315009.71 had the highest specific gravity, dry matter content, and total starch content (Table 6). These differences might be related to genetic variations among potato genotypes. Furthermore, higher dry matter content in these genotypes indicates that starch and dry matter contents of potatoes are directly

related to each other. Genotypes with high specific gravity showed a 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. Among the studied genotypes, genotype CIP315008.160 exhibited the lowest specific gravity, dry matter content, and total starch content. According to [44] among the evaluated 32 potato genotypes in Pakistan, the genotypes had 1.03-1.14 g/cm³ for specific gravity, 14.86-25.65% for dry matter content, and 9.00-20.01% for total starch content. These variations could be associated with genetic differences among potato genotypes. Additionally, greater dry matter levels in these genotypes are directly associated with the starch and dry matter contents of potatoes. Genotypes exhibiting elevated specific gravity demonstrated greater percentages of dry matter content and total starch content. This indicated the necessity for ongoing assessment of these breeding materials, enabling breeders to recognize and acquire genotypes with superior tuber quality characteristics for upcoming breeding initiatives. Asmamaw [45] and Elfnes [46] found specific gravity ranges of 1.064 to 1.094 and 1.078 to 1.10, respectively.

Similarly, [47] noted specific gravity values ranging from 1.065 to 1.077 based on research involving eight varieties over two successive years. Tesfaye [48] evaluated 25 released potato varieties, and the overall values of the varieties 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. Wassu [38] examined varieties across three sites: Haramaya, Hirna, and Arberkete, finding that the tuber specific gravity, dry matter content, and starch content varied from 1.065 to 1.097 g/cm³, 19.49 to 26.98%, and 10.71 to 16.88%, respectively. Aggarwal [49] found that tuber internal quality varied 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. Tessema [50] noted that Belete had the highest tuber specific gravity at 1.102, which was significantly different from other potato varieties, while Menagesha showed the lowest tuber specific gravity at 1.057. Of the varieties examined, the highest percentage of dry matter was noted in the Belete variety (25.417), followed by Challa (23.625), while the lowest percentage of dry matter was observed in the Menagesha variety (15.708). According to findings reported by [51], genotypes varied for specific gravity, dry matter content, and total starch content, which ranged from 1.070 to 1.103 g/cm³, 18.67 to 25.75%, and 12.64% to 18.95%, respectively. A study by Tesfaye [52] and Ismail [53], indicates that the interaction between the

growing environment and cultivars significantly affects the dry matter content and specific gravity of tubers.

Table 6 :- Mean performance of 15 potato genotypes for quality traits evaluated at Bekoji in 2022 and 2023

S/No	Genotypes	Dry matter (%)	Specific gravity	Total starch (g/100 g)
1	CIP315004.61	21.89 ^{a-d}	1.09 ^{a-c}	15.39 ^{a-d}
2	CIP315009.30	21.49 ^{b-d}	1.085 ^{bc}	15.04 ^{b-d}
3	CIP315010.161	21.69 ^{a-d}	1.09 ^{a-c}	15.21 ^{a-d}
4	CIP315003.132	22.25 ^{a-c}	1.09 ^{ab}	15.75 ^{a-c}
5	CIP315004.113	19.9 ^{de}	1.08 ^{cd}	13.62 ^{de}
6	CIP315008.160	18.32 ^e	1.07 ^d	12.03 ^e
7	CIP315003.83	20.29 ^{c-e}	1.08 ^{cd}	13.89 ^{c-e}
8	CIP315003.166	20.75 ^{b-d}	1.08 ^{bc}	14.33 ^{b-d}
9	CIP315003.25	22.45 ^{ab}	1.09 ^{ab}	15.93 ^{ab}
10	CIP315009.71	23.66 ^a	1.097 ^a	17.08 ^a
11	CIP315009.70	22.44 ^{ab}	1.092 ^{ab}	15.93 ^{ab}
12	CIP315008.182	20.51 ^{b-d}	1.08 ^{b-d}	14.12 ^{b-d}
13	CIP315004.13	22.22 ^{a-c}	1.09 ^{a-c}	15.72 ^{a-c}
14	Burka	22.12 ^{a-c}	1.09 ^{ab}	15.62 ^{a-c}
15	CIP315008.154	21.44 ^{b-d}	1.08 ^{bc}	14.99 ^{b-d}
Mean		21.43	1.09	14.98
Range		18.32 -23.66	1.07- 1.097	12.03- 17.08
CV (%)		8.50	0.89	11.47
P-value		< 0.001	< 0.001	< 0.01

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

3.4 Mean performances of genotypes for yield components and yield

The examined potato genotypes exhibited a broad spectrum of variation in overall tuber yield, varying from 38.76 to 61. 94 t ha⁻¹, with an average yield of 49. 99 t ha⁻¹ (Table 7). The average total tuber yield of the released variety (Burka) ranged from 21.48 to 38.83 t ha⁻¹. The four advanced clones CIP315003.132, CIP315008.160, CIP315009.71, and CIP315004.61 produced a

total tuber yield that exceeded the average tuber yield of the released variety, Burka. Nonetheless, genotype CIP315003.83 produced a low overall tuber yield. Marketable tuber yield varied between 35.79 and 57.57 t ha⁻¹, with an average performance of 46.34 t ha⁻¹.

The five advanced clones produced a greater total tuber yield compared to the released variety (Burka). The four advanced clones CIP315003.132, CIP315008.160, CIP315009.71, and CIP315004.61 yielded a total tuber yield higher than the mean tuber yield of the released variety, Burka. The average late blight severity (%) varied from 3.00 to 15.67, with an overall average of 6.48. The greatest late blight severity (15.67%) was observed in CIP315003.166, while the least severity (3.00%) was noted in CIP315003.25 (Table 7). The average tuber weight of the assessed genotypes varied from 222.37 to 452.35 g, with a total mean of 304.89 g. The genotype CIP315004.61 recorded the highest average tuber weight, while CIP315003.83 recorded the lowest average tuber weight. The average tuber bulking rate of the assessed genotypes varied from 835.07 to 1440.89 g/day, with a total mean of 1159.54 g/day. The genotype CIP315003.132 recorded the highest average tuber bulking rate, while CIP315004.113 recorded the lowest average tuber bulking rate (Table 7).

Aseffa [54], indicated that potato genotypes exhibited a broad spectrum of variations. Total tuber yield varied between 0.8 to 46.1 t ha⁻¹, averaging at 19.4 t ha⁻¹. Addisu [35], and Baye [55] also indicated that certain newly introduced potato genotypes produced higher tuber yields compared to current commercial potato varieties. This demonstrated the existence of variation in the genotypes examined for total tuber yield, which can be utilized to enhance the crop. According to Hunde [56], the mean total tuber yield and marketable tuber yield ranged from 21.63 to 48.69 and 11.94 to 38.01 t ha⁻¹, with an overall mean total tuber yield of 31.37 t ha⁻¹.

According to Getachew [57], the mean total tuber yield of genotypes across environments ranged from 45.75 to 25.27 t ha⁻¹. Likewise, Awoke [58] reported that the maximum total tuber number was recorded from genotype CIP-395123.6 (4.8), followed by Gudanie (4.5), while the lowest tuber number per hill was recorded from CIP-3956023.109. This indicated the existence of differences in the genotypes examined for overall tuber yield that can be utilized to enhance the crop. The same genotypes showed the highest yield of marketable tubers and the highest number of marketable tubers per hill, along with the lowest yield of unmarketable tubers and the lowest number of unmarketable tubers per hill.

Table 7:- Mean performance of 15 potato genotypes for yield and yield components traits evaluated at Bekoji in 2022 and 2023

S/N o	Genotypes	Total marketable yield(t/ha)	Total unmarketable yield(t/ha)	Total yield(t/ha)	Late blight	Average tuber weight(g)	Tuber bulking rate(g/days)
1	CIP315004.61	54.76 ^{ab}	3.28 ^{cd}	58.04 ^{ab}	4.72 ^{e-i}	452.35 ^a	1183.07 ^{a-e}
2	CIP315009.30	49.81 ^{a-c}	2.95 ^d	52.7 ^{a-c}	5.40 ^{d-i}	339.54 ^{cd}	1035.68 ^{c-f}
3	CIP315010.161	37.89 ^{c-e}	5.22 ^a	43.12 ^{c-e}	6.57 ^{d-f}	271.17 ^{de}	1047.64 ^{c-f}
4	CIP315003.132	57.57 ^a	4.36 ^{a-c}	61.94 ^a	3.92 ^{g-i}	256.89 ^{de}	1440.89 ^a
5	CIP315004.113	37.27 ^{c-e}	3.81 ^{b-d}	41.08 ^{c-e}	7.47 ^{cd}	426.77 ^{ab}	835.07 ^f
6	CIP315008.160	55.18 ^{ab}	4.19 ^{a-c}	59.38 ^{ab}	5.93 ^{d-g}	341.45 ^{b-d}	1299.61 ^{a-d}
7	CIP315003.83	35.79 ^e	2.97 ^d	38.76 ^e	10.10 ^b	222.37 ^e	968.86 ^{d-f}
8	CIP315003.166	39.14 ^{c-e}	3.04 ^d	42.17 ^{c-e}	15.67 ^a	288.16 ^{c-e}	943.30 ^{ef}
9	CIP315003.25	47.59 ^{a-e}	4.60 ^{ab}	52.19 ^{a-d}	3.00 ⁱ	260.10 ^{de}	1170.04 ^{a-e}
10	CIP315009.71	54.92 ^{ab}	4.25 ^{a-c}	59.17 ^{ab}	3.25 ^{hi}	365.79 ^{bc}	1303.45 ^{a-c}
11	CIP315009.70	36.42 ^{de}	3.28 ^{cd}	39.69 ^{de}	5.82 ^{d-h}	264.61 ^{de}	1225.58 ^{a-e}
12	CIP315008.182	47.73 ^{a-e}	3.06 ^d	50.79 ^{a-e}	4.55 ^{e-i}	298.54 ^{c-e}	1194.09 ^{a-e}
13	CIP315004.13	43.79 ^{b-e}	3.02 ^d	46.79 ^{b-e}	10.05 ^{bc}	243.17 ^e	1082.72 ^{b-f}
14	Burka	48.29 ^{a-e}	3.55 ^{b-d}	51.85 ^{a-d}	6.73 ^{de}	282.71 ^{c-e}	1392.09 ^{ab}
15	CIP315008.154	48.93 ^{a-d}	3.35 ^{cd}	52.28 ^{a-d}	3.98 ^{f-i}	259.83 ^{de}	1270.95 ^{a-e}
	Range	35.79- 57.57	2.95-4.60	38.76-61.94	3.00-15.67	222.37-452.35	835.07-1440.89
	Mean	46.34	3.66	49.99	6.48	304.89	1159.54
	CV (%)	24.34	26.75	22.47	34.92	24.37	24.77
	P-value	< 0.001	< 0.001	< 0.01	< 0.001	< 0.001	< 0.01

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

3.5 Potato Late Blight Severity

The Area Under the Disease Progress Curve (AUDPC) was computed to assess the progression of late blight in different potato genotypes. Based on the calculated AUDPC, the five genotypes, namely CIP315003.25, CIP315009.71, CIP315003.132, CIP315008.154, and CIP315008.182, had the lowest AUDPC, ranging from 99.17 to 139.17, while the others had the highest range, i.e., 208.33 to 449.17. None of the genotypes had a disease score of 1. The genotypes that scored lower disease severity and AUDPC also had higher marketable tuber yields. The lowest unmarketable tuber yields were registered for CIP315009.30, CIP315003.83, CIP315003.166, and CIP315004.13, while the highest was recorded for CIP315010.161, followed by CIP315003.25 and CIP315003.132 (Table 8).

As reported by [36] based on the computed AUDPC, the five varieties-Bulle, Bubu, Belete, Araarsaa, and Gera-exhibited the lowest AUDPC values, between 125 and 544, while the remaining varieties showed a higher range, from 704 to 2994. According to [59] the highest AUDPC value at 2056.05 and the lowest AUDPC value was recorded in CIP 395111.13 at 695.01, indicating relatively lower disease progression compared to other genotypes. Ahmed [60] reported that the disease-resistant varieties Belete, Degemegn, and Guassa were recognized as resistant to late blight, while Gudene, Jalene, and Local are identified as susceptible varieties under irrigation circumstances in Alichu Wuriro District.

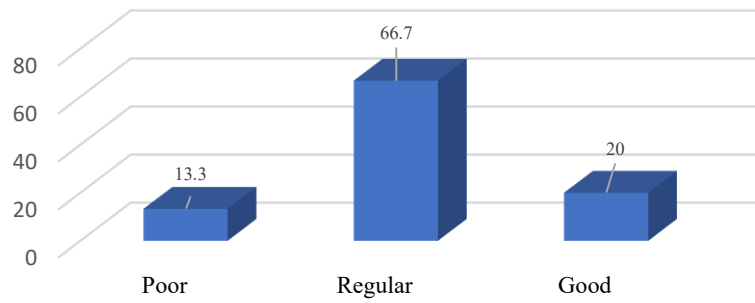
Table 8:- Mean performance of 15 potato genotypes late blight reaction evaluated at Bekoji in 2022 and 2023

S/No	Genotypes	AUDPC_by_mean	Std	Reaction
1	CIP315003.25	99.17	30.97	Resistant
2	CIP315009.71	112.08	24.31	Resistant
3	CIP315003.132	114.58	74.07	Resistant
4	CIP315008.154	130.00	56.32	Resistant
5	CIP315008.182	139.17	83.15	Resistant
7	CIP315004.61	157.08	67.22	Moderately Resistant
8	CIP315009.30	167.50	53.06	Moderately Resistant
9	CIP315010.161	189.58	42.88	Moderately Resistant
10	CIP315009.70	190.83	51.54	Moderately Resistant
11	CIP315008.160	193.75	27.56	Moderately Resistant
12	Burka	208.33	59.87	Susceptible
13	CIP315004.113	240.83	104.85	Susceptible
14	CIP315003.83	277.50	91.39	Susceptible
15	CIP315004.13	291.25	139.67	Susceptible
16	CIP315003.166	449.17	237.03	Susceptible

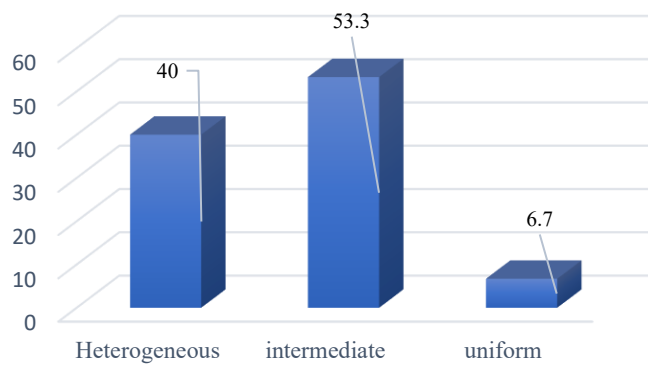
3.6 Qualitative traits of tubers

The highest proportion of genotypes had a regular tuber appearance (66.7%), intermediate tuber uniformity (53.3%), shallow tuber eye depth (73.3%), obovate and long-oblong tuber shape (33.3%) (Figure1(a-d)). A small proportion of genotypes had poor tuber appearance (13.3%), uniform tuber uniformity (6.7%), deep tuber eye depth (6.7%), and compressed and elongate tuber shape (6.7%). The research conducted by [61] indicated that potato tubers should be uniform in size and have a round to oval shape. Abbas [44] reported 59.38% white tuber skin color, 81.25% oval tuber shape, and 71.88% shallow eye depth, and 65.63% cream flesh color observed in 32 potato genotypes, indicating oval-shaped tubers with shallow to medium eyes. Seid and Tessema [51] demonstrated that the largest percentage of genotypes exhibited ovate and elliptic tuber shape (25%) and shallow eye depth (50%). A minor percentage of genotypes exhibited compressed and obovate tuber shape (8.33%) as well as deep and very deep eye depth (12.5%).

a. % of tuber appearance



b. % of tuber uniformity



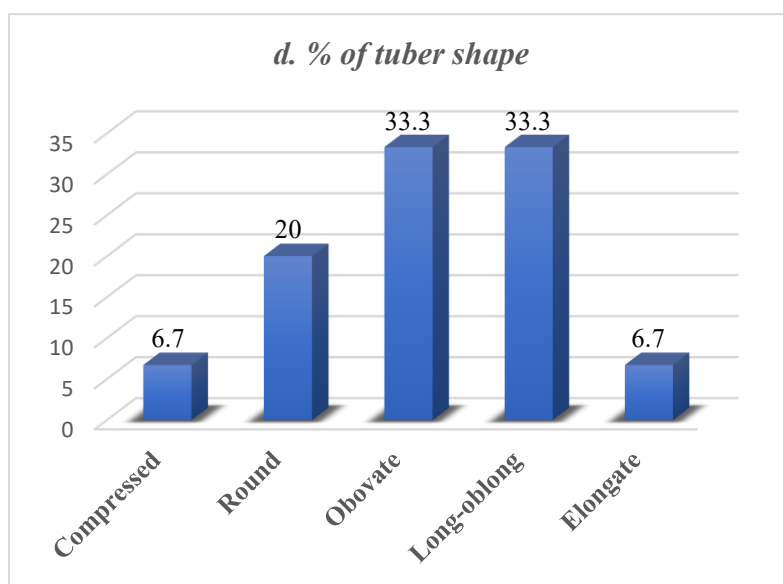
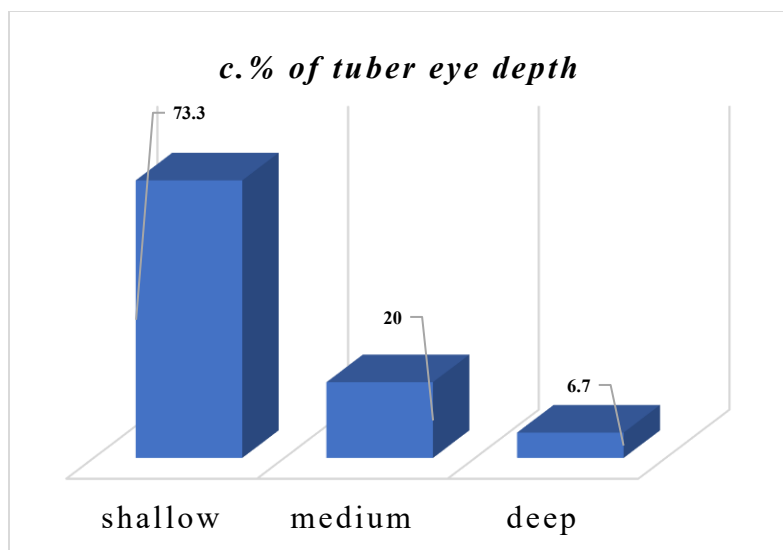


Fig:- 1. Distribution of 15 potato genotypes into different categories of qualitative traits a tuber appearance, b tuber uniformity, c tuber eye depth and d tuber shape.

3.7 Pearson's Correlation Analysis

To improve crop yield or plant structure, selection must be based on the association of related features, which measures the interrelationships between different plant traits and identifies constituent traits on which breeding can be based to improve crops[62-63]. The Pearson correlation between the thirteen traits indicated that total tuber yield was strongly and positively correlated with marketable tuber yield ($r = 1.00^{***}$) and tuber bulking rate ($r = 0.62^{**}$). Total tuber yield was positively correlated with average tuber weight ($r = 0.40^{***}$) and plant height (r

= 0.39 **) , indicating the importance of these traits for the improvement of tuber yield in potato (Figure. 2).

A highly strong and positive correlation was also observed between total starch content, dry matter content ($r = 0.96^{***}$), and specific gravity ($r = 0.96^{***}$). Average tuber weight showed a strong and positive correlation with marketable tuber yield and total tuber yield. On the other hand, average tuber weight was negatively and significantly correlated with average stem number per plant. Tuber bulking rate showed a highly strong and positive correlation with days to 50% flowering date ($r = 0.36^{***}$), marketable tuber yield per hectare ($r = 0.62^{***}$), and total tuber yield ($r = 0.62^{***}$) (Fig. 2). Luthra [64], reported that marketable tuber yield was highly significant and positively correlated with total tuber yield ($r = 0.99^{**}$).

According to [65], tuber weight was strongly and positively correlated with yield ($r = 0.8$). A strong positive correlation was also observed between the total number of tubers and the number of tubers per plant. The above results were similarly reported by Workayehu [66], who found marketable tubers had a positive and significant association with total tuber yield.

According to [6], total tuber yield was strongly and positively correlated with marketable tuber yield ($r = 0.98^{***}$) , and a positive correlation was also observed between fat content and marketable tuber yield, total tuber yield, and average tuber yield. Average tuber weight showed a strong and positive correlation with marketable tuber yield and total tuber yield. Similarly, a positive and significant correlation between marketable tuber yields and total tuber yield was reported by Panigrahi [67]. Average tuber weight with total tuber yield has been reported by Rahman [68].

Chindi [69] emphasized that specific gravity, highly correlated with dry matter content, directly influences processing quality. Higher specific gravity results in better processing yield, reduced oil absorption, and improved texture. Similar findings [70], reported significant correlations ($p \leq 0.05$) between the characteristics, suggesting that there is an opportunity for trying indirect selection for the characteristic with the largest heritability to maximize genetic gains.

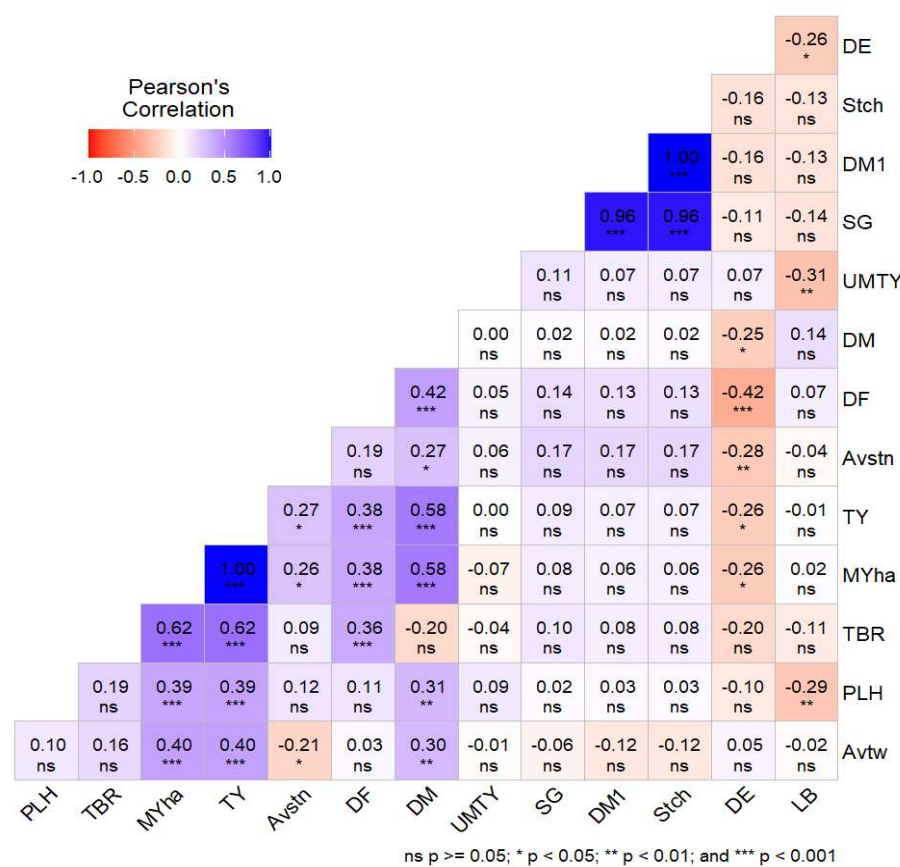


Figure :- 2. Pearson correlation coefficient among variables. DE= days to 50% emergency, DF= days to 50%flowering, DM= days to 90% physiological maturity, PH= plant height (cm), Avstn= Average stem number per plant, DM1= Dry matter content(%),SG=Specific gravity, Stch=Strach content, MYT/ha= Marketable yield /ha, UMTY= Unmarketable yield/ha, TY=Total yield/ha, Avtw=average tuber weight, TBR=Tuber bulking rate

4.Conclusion

In summary, this research demonstrated a notable difference among potato genotypes in their tuber production, yield factors, and external and internal traits related to quality. This will offer a valuable opportunity for breeders to choose genotypes with superior tuber yield performance and characteristics that meet processing standards . Ultimately, based on both external and processing quality characteristics, the potato genotypes CIP315004.61, CIP315009.30, CIP315003.132, CIP315009.71, and CIP315008.154 might be more suitable for processing and potato tuber yield. The genotypes that possess either superficial or moderate eye depth might be permissible for evaluating quality characteristics. Potato genotypes exhibiting favorable yield and processing quality characteristics could also serve as parents for upcoming crossing programs in Ethiopia.

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Author contributions

All authors contributed to the study conception and design. Dasta Tsagaye: Conceptualization, Methodology, Trial management, Data Management, Analyzing, and writing the original draft. Demis Fikre: Supervision, Data curation, Writing review & editing. Gizaw Wogayew: Data Curation, Writing review and editing. Misgana Banti: Writing review and editing. Nimona Fufa: Writing review and editing. Kedir Jaleto: Writing review and editing. All authors read and approved the final manuscript.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable. This study did not involve human or animal experimentation requiring formal institutional ethical approval.

Consent for publication

Not applicable. This manuscript does not contain any personal data, images, or identifiable individual information that requires individual consent for publication. All data presented are aggregated and anonymized .

Competing interests

The authors declare no competing interests.

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