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Agronomic Evaluation of Potato (*Solanum tuberosum* L.) Genotypes for Tuber Yield and Yield Attributing Traits

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ABSTRACT

The experiment was carried out under rain fed conditions for three consecutive years (2017–2019) from mid-June to mid-October at Bekoji and Kofele sub sites of Kulumsa Agricultural Research Center, Ethiopia by using improved varieties to identify superior genotypes. The experiment was laid out in a randomized complete block design with three replications. The results of analysis of variance (ANOVA) showed that the presence of significant ($p<0.05$) differences among genotypes for all traits studied. Analysis of variance revealed that location by year effect had highly significant difference at ($p<0.01$) for all traits except specific gravity which showed significant difference at ($p<0.05$). Treatment by location showed significant difference except stem number plant^{-1}, total yield, and specific gravity. Treatment by year showed significant differences except for days to flowering. The highest marketable tuber yield was obtained from genotype CIP 395037.107 followed by variety Belete and CIP 395015.6 genotype. Simple correlation analysis revealed that total tuber yield showed strongly and positively significant correlation with average stem number plant^{-1}, stem height and marketable yield. Thus, it could be concluded that genotypes, year and location variations as well as their interaction had considerable influence on tuber yield and the potato's attributes. The significant interaction effects of genotypes, location, year and positive and strong association between total yield and other traits indicates the need to test potato genotypes over season and location in order to select stable and high yielder genotypes.

KEYWORDS: Environment, genotype, marketable tuber yield, total tuber yield

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1. INTRODUCTION

Potato (*Solanum tuberosum* L.) belongs to the family, Solanaceae, it is the most important non-grain crop and fourth most important crop in terms of global production (Anonymous, 2019) and the first among the root and tuber crops, which includes cassava (*Manihot esculenta*), sweet potato (*Ipomea batatas*) and yam (*Dioscorea* spp.) (Anonymous, 2004). Potato (*Solanum tuberosum* L.) is a versatile commodity adapted to a wide range of agro-ecologies and an indication of its potential for further expansion in various ecosystems. Potatoes can grow up to 4,700 m above sea level, from southern Chile to Greenland (Anonymous, 2017).

Potato is grown in more than 150 countries, a staple food of about one billion people in the world in which about a half is localized in the developing counties (Anonymous, 2019). 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; are all home to more than seven million smallholder potato farmer households (Abdulwahab et al., 2016). Globally, more than one and more billion people eat potatoes as a staple food (Ahmed et al., 2018, Chen et al., 2021). Global potato production has increased by about 20% since 1990, although production is still 50% below that of wheat, maize, and rice (Anonymous, 2019). It is produced for fresh potato tubers is about 359 mt from a total area of 16.5mha (Anonymous, 2020). 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).

In Ethiopia it ranks first among root and tuber crops (Anonymous, 2016). Potato is characterized as a cheap and nutritious food security crop (Beals, 2019). Potatoes are very rich in various nutrients such as carbohydrate, amino acid, vitamins, minerals, antioxidant, dietary fibers, and protein (Burgos et al., 2020). The protein of potato was reported to be very rich in lysine and low in sulphur holding amino acids and potatoes are nearly free of fat and cholesterol as opposed to other staple food (Kowalczewski et al., 2019). Potato tubers provide raw materials to industries producing chips, crisps, starch, spirits and alcohol (Sriom et al., 2017, Das et al., 2021). Potato considered as a food security crop that helps to meet the rising of food demands in the tropical highlands of Sub-Saharan Africa (Kolech, 2019). The farming systems of potato production in Africa vary from 25 t, and 35 t in South Africa (Muthoni et al., 2022). It is an extremely important crop for countries such as Ethiopia, where inadequate protein and supplies of calories are apparent nutritional problems (Erokhin et al., 2021, Chindi et al., 2017). It also provides employment opportunities in the production, processing, and marketing chains (Hedberg and Lounsbury, 2021).

Potato is grown in four major areas in Ethiopia: the central, the eastern, the north- western and the southern regions. Together, these areas cover approximately 83% of the potato farmers (Anonymous, 2008/2009). In the 2019 and 2020 central statistics agency reports, average national potato productivity in Ethiopia was 13.62 t ha^{-1} and 13.13 t ha^{-1} during 2019 and 2020 respectively (Anonymous, 2019/2020) and its productivity is very low as compared the world, especially the leading country China, because of many challenges (Saxena, 2014). Among the main challenges causing this low potato productivity limited number of improved and high yielding potato varieties adapted to current biotic and abiotic stresses worsened by the current climate changes (Rukundo et al., 2019). Assessment of genotype×environment interactions and adaptation to wide environment would benefit growers. Hence, the experiment was proposed to identify high yielding genotypes/genotype adapted to wide southern eastern Ethiopia.

2. MATERIALS AND METHODS

2.1. Description of the study sites

The experiment was carried out under rain fed conditions for three consecutive years (2017–2019) from mid-June to mid-October at Bekoji and Kofele sub sites of Kulumsa Agricultural Research Center (Table 1).

Table 1: Description of the study areas

Descriptions	Bekoji	Kofele
Altitude	2780	2660
Latitude	070 32' 37''N	070 04' 28''N
Longitude	390 15' 21''E	380 47' 11'' E
Rainfall (mm)	1020	1211
Tmin (oc)	7.9	7.1
Tmax (oc)	18.6	18
Soil type	Clay soil (Nitosols)	Heavy clay soil (Vertsols)
Soil pH	5	5.2

Source: Ethiopian Meteorological Agency branch at Bekoji and Kofele (2013)

2.2. Description of experimental materials

Table 2: List of experimental materials included in the study

Sl. No.	Treatments	Remarks
1.	CIP 396244.12	Genotype
2.	CIP396029.205	Genotype
3.	CIP 395084.9	Genotype
4.	CIP 395015.6	Genotype
5.	CIP 395123.6	Genotype
6.	CIP 396009.239	Genotype
7.	CIP 396027.111	Genotype
8.	CIP 395169.17	Genotype
9.	CIP 395037.107	Genotype
10.	CIP 395077.12	Genotype
11.	Gudanie	Released Variety
12.	Belete	Released Variety
13.	Dagim	Released Variety

Genotypes, used for the evaluation, were from Holeta Agricultural Research Centre

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 9 m^2 with spacing of at 0.75 m to 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. Collected data

The following data were recorded; days to 50% emergence (days), days to 50% flowering (days), days to maturity (days), number of main stem $hill^{-1}$, plant height (cm), marketable tuber yield (t ha^{-1}), unmarketable tuber yield (t ha^{-1}), total tuber yield (t ha^{-1}) and specific gravity was calculated as suggested by Gould (1995).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

2.7. 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 and years 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 were conducted based on pooled mean performance over the locations using LSD test at a 5% level of significance. Analysis of variance in randomized complete block design was computed using the following model:

Yij=+rj+gi+εij……………………(1).

Where, Yij=the response of trait Y in the i^{th} genotype and the j^{th} replication=the grand mean of trait Y rj=the effect of the j^{th} replication gi=the effect of the ith genotype εij=experimental error effect

3. RESULTS AND DISCUSSION

3.1. Analysis of variance

The results of analysis of variance (ANOVA) showed that the genotypes had significant ($p<0.05$) differences for all traits. Analysis of variance revealed that location by year interaction showed highly significant difference at ($p<0.01$) for all traits except specific gravity which showed significant difference at ($p<0.05$). Treatment by location showed significant difference except stem number per plant, total yield, and specific gravity. Treatment by year showed significant difference except days to flowering (Table 3).

A study Chindi et al. (2021) reported that the evaluated clones were highly significant different growth performance for, tuber yield, and quality traits except for average tuber weight ($p<0.01$). According to Rukundo et al. (2019) the effects of genotype, location, season, genotype×location, location×season, genotype×season, and genotype×site×season were significant for marketable and non-marketable yields. According to Tesfaye et al. (2013) reported that highly significant differences among potato clones for average tuber number $hill^{-1}$ and average tuber weight.

3.2. Mean values for yield and yield components

Among tested potato clones, the highest stem number $plant^{-1}$ (6.58) was observed for CIP 395015.6, while the clone CIP 395077.12 produced a low stem number per plant (2.59) (Table 4). According to Alemayew et al. (2018) the highest numbers of main stem $plant^{-1}$ were recorded on Bule (4.917), Gudenie (4.333), Jalenie (4.583) and Belete (4.000) varieties while the lowest on Degemegni (2.500) and local variety Key Dench (3.083). The highest plant height was recorded for clone CIP396029.205 followed by Belete variety and CIP 395015.6 clone. According to Tesemma et al. (2020) the maximum plant height was recorded from Gorebella (74.2 cm) whereas the minimum plant height was recorded from Menagesha (38.9 cm). Highest marketable tuber yield was recorded from CIP-395037.107 (46.69

Table 3: Mean squares from combined analysis of variances over locations and years for 9 traits of potato genotypes in 2017 to 2019

Source variation	DF	DE	DF*	DPM	SH (cm)	SN	MTY (t ha^{-1})	UMTY (t ha^{-1})	TTY (t ha^{-1})	SG
Location	1	4.65	1844.65**	15.84	1.1	765.92*	123562.41**	332.63	111076.14*	0.04**
Year	2	446.12**	229.55**	10888.0**	12.35**	296.38*	373465.60**	4128.51*	387163.31**	0.062**
Rep (Loc)	3	36.1*	46.18*	35.34*	2.25	160.99*	11005.5	1889.13	17641.8	0.002
Genotype	12	20.00*	218.21**	304.16**	28.20**	1655.68**	163184.0**	4215.66**	202175.61**	0.004*
Loc.×Year	2	133.2**	1231.74**	270.5**	79.52**	874.51**	86382.1**	35958.50**	131260.24**	0.02*
Loc×Genotype	12	20.04*	34.65*	39.25*	0.74	125.46*	5819.7	3425.17*	12638.2	0.001
Year×Genotype	24	37.1**	15.29	72.69**	3.97**	158.58**	16586.6*	3650.93**	15416.80*	0.005*
Loc×Year×Gen	24	14.19*	9.7	15.42	3.58**	97.47*	21913.70*	1835.65*	30035.63**	0.001
Error	153	7.62	11.04	11.39	1.3	56.21	8107.22	1133.01	9554.19	0.002
Mean		18.32	64.67	107.78	4.44	69.93	298.22	56.4	357.59	1.11
CV (%)		15.1	5.14	3.13	25.72	10.72	30.2	56.7	27.33	4.18
R^2		72.3	83.65	94.32	78.45	78.54	76.62	64.4	77.1	55.3

DF: Degree freedom; DE: Days to emergence; DF*: Days to 50% flowering; DPM: Days to physiological maturity; SH (cm): Stem height (cm); SN: Stem number^{-1}; MTY: Marketable tuber yield (t ha^{-1}); UMTY: Unmarketable tuber yield (t ha^{-1}); TTY: Total tuber yield (t ha^{-1}); SG: Specific gravity; CV: Coefficient variation

Table 4: Mean performances of potato genotypes for tuber yield and yield related traits evaluated at Bekoji and Kofele in 2017 to 2019

Clones	DE	DF	DPM	SN	SH	MTY (t ha^{-1})	UNMY (t ha^{-1})	TTY (t ha^{-1})	SG
CIP 396244.12	19.56^{a}	60.06^{f}	104.94^{e}	5.37^{bc}	76.09^{bcd}	25.07^{c}	6.07^{b-d}	31.16^{c}	1.090^{cd}
CIP396029.205	18.94^{ab}	60.0^{f}	104.17^{e}	5.36^{bc}	81.2^{a}	25.03^{c}	5.54^{cd}	30.56^{c}	1.083^{d}
CIP 395084.9	17.67^{bc}	58.83^{f}	103.0^{e}	4.94^{cd}	56.89^{f}	22.82^{cd}	38.78^{d}	26.69^{cde}	1.103b-d
CIP 395015.6	17.56^{bc}	66.89^{bc}	103.94^{e}	6.58^{a}	77.62^{a-c}	37.300^{b}	7.30^{a-c}	44.57^{b}	1.109^{a-d}
CIP 395123.6	19.56^{a}	66.89^{bc}	113.72^{a}	2.59^{f}	54.44^{f}	19.04^{de}	4.28^{d}	23.32^{de}	1.11^{abc}
CIP 396009.239	17.0^{c}	64.83^{cd}	108.33^{d}	4.46^{d}	78.08^{a-c}	35.32^{b}	6.77^{a-c}	42.08^{b}	1.105^{b-d}
CIP 396027.111	17.61^{bc}	66.50^{bc}	108.94^{cd}	4.42^{d}	58.98^{f}	24.94^{cd}	4.33^{d}	29.26^{cd}	1.11^{a-c}
CIP 395169.17	18.22^{a-c}	70.72^{a}	113.33^{a}	3.43^{e}	74.09^{c-e}	16.47^{e}	4.27^{d}	20.74^{e}	1.14^{a}
CIP 395037.107	19.83^{a}	66.50^{bc}	112.72^{ab}	3.43^{e}	71.47^{de}	46.79^{a}	6.80^{a-c}	53.49^{a}	1.12^{ab}
CIP 395077.12	19.78^{a}	65.72^{b-d}	110.17^{cd}	2.59^{f}	69.22^{e}	33.40^{b}	8.04^{ab}	41.43^{b}	1.12^{ab}
Gudanie	17.44^{bc}	67.5^{b}	103.17^{e}	6.06^{ab}	73.92^{c-e}	33.20^{b}	8.65^{a}	41.85^{b}	1.095^{b-d}
Belete	17.72^{bc}	63.94^{de}	110.83^{bc}	3.65^{e}	79.59^{ab}	45.21^{a}	6.50^{b-d}	51.26^{a}	1.11^{a-c}
Dagim	17.28^{bc}	62.33^{e}	103.83^{e}	4.84^{cd}	57.53^{f}	23.24^{cd}	5.21^{cd}	28.44^{cd}	1.12^{ab}
Mean	18.32	64.67	107.78	4.44	69.93	29.82	5.94	35.76	1.11
LSD	1.892	2.18	2.22	0.75	4.94	59.29	2.28	6.44	0.03
CV (%)	15.07	5.14	3.13	25.72	10.72	30.19	5.70	27.33	4.19

DE: Days to emergence; DF: Days to 50% flowering; DPM: Days to physiological maturity; SH (cm): SN: Stem number^{-1}; Stem height (cm); MTY: Marketable tuber yield (t ha^{-1}); UMTY: Unmarketable tuber yield (t ha^{-1}); TTY: Total tuber yield (t ha^{-1}); SG: Specific gravity; CV: Coefficient variation

tha^{-1}) and followed by standard check Belete (45.21 t ha^{-1}); whereas the lowest marketable tuber yield was recorded from CIP-395084.9 (22.82 t ha^{-1}) followed by check Dagim (23.35 t ha^{-1}) (Table 4). Habtamu et al. (2016) indicated that marketable tuber yield was influenced by the genotype, growing environment and the interaction effect of the genotype and growing environment. Other researcher reported investigated that marketable yield was significantly varied by variety, location and genotypes× environment interaction (Mendes, 2022). The clones CIP 395169.17, CIP 396027.111, CIP 395084.9, CIP396029.205, CIP 396244.12 and CIP 395084.9, showed the yields ranging between 20 and 31 tha^{-1}, while the standard checks Belete and Gudanie gave the yields of 51 and 41 tha^{-1}, respectively.

The genotypes were varied for specific gravity which ranged from 1.14 to 1.083 g cm^{-3}. The highest specific gravity recorded for CIP 395169.17 (1.14 g cm^{-3}) and CIP396029.205 (1.083 g cm^{-3}) (Table 4). According to Silva et al. (2014), Chindi et al. (2021) the specific gravity is an important trait, which is directly related to the dry matter content of the tubers. Higher specific gravity provides higher processing yield, less fat absorption, better texture without affecting the taste of the final product. On the other hand, lower sugar content prevents the darkening of the processed products, which compromises the appearance and flavor of the fried product (Silva et al., 2014, Chindi et al., 2021).

3.3. Correlation coefficient analysis

The relationship between yield and agronomic traits is important to the plant breeders to find out the traits correlated with yield and also how they are associated among themselves. Correlation analysis showed that days to emergence ($r=0.5^{***}$) strongly associated with days to maturity and it was negatively correlated with marketable tuber yield ($r=-0.15^{*}$). Days to 50% flowering was highly and negatively correlated with average stem number per plant ($r=-0.30^{**}$) it was and negatively correlated with specific gravity($r=-0.16^{*}$); days to maturity showed highly significantly and positively correlated with days to emergence ($r=0.50^{***}$) but significantly and negatively correlated with average stem number $plant^{-1}$($r=-0.33^{***}$), marketable tuber yield ($r=-0.24^{***}$) and total yield ($r=-0.22^{***}$) the same trait was positively and significantly correlated with specific gravity($r=0.14^{*}$).

Average stem number $plant^{-1}$ had significant and negatively correlated with days to emergence days to 50% flowering ($r=-0.06^{***}$ and $r=-0.30^{**}$) respectively, the same trait had significant positively correlated with marketable tuber yield and total yield ($r=0.20^{*}$ and $r=0.16^{*}$) respectively. Average stem height (cm) positively significant and positively correlation with marketable tuber yield, unmarketable tuber yield and total yield ($r=0.29^{***}$, $r=0.26^{***}$ and r=0.34) respectively; on the other hand negatively significant correlation was observed b/n stem height and specific gravity (r=-0.22). Marketable tuber yield showed strongly and positively correlated with average stem number per $plant^{-1}$, stem height and total yield ($r=0.20^{***}$, $r=0.29^{***}$ and $r=0.96^{**}$) respectively, but it had negative and correlation with days maturity and specific gravity (r=-0.24 and r=-0.17).

Unmarketable tuber yield showed strongly and positive correlation with stem height, marketable yield and total yield ($r=0.26^{***}$, $r=0.18^{***}$ and $r=0.44^{**}$) respectively. Total tuber yield showed strongly and positively significant correlation with average stem number $plant^{-1}$, stem height and marketable yield ($r=0.16^{***}$, $r=0.34^{***}$ and $r=0.96^{**}$) respectively, it had negative and correlation with specific gravity ($r=-0.15^{*}$). Specific gravity showed negative and correlation with days to flowering, average stem number per plant and stem height ($r=-0.16^{***}$, $r=-0.12^{***}$ and $r=-0.22^{**}$) respectively. The same trait had and positive significant correlation with unmarketable tuber yield($r=0.004^{*}$) (Table 5).

Table 5: Pearson's correlation (r) of potato tuber yield and its components of potato varieties and genotypes

Traits	DE	DF	DPM	SH	SN	MTY	UTY	TTY	SG
DE	1.00	-0.08	0.50^{***}	-0.06	0.05	-0.15	0.10^{*}	-0.11	0.12
DF	-0.08	1.00	0.13	-0.30^{***}	0.09	0.06	0.00	0.05	-0.16^{*}
DM	0.50	0.13	1.00	-0.33^{***}	0.05	-0.24^{***}	0.00	-0.22^{***}	0.14^{*}
SN	-0.06^{****}	-0.30^{***}	-0.33	1.00	0.12	0.20^{**}	-0.08	0.16^{**}	-0.12
SH	0.05	0.09	0.05	0.12	1.00	0.29^{***}	0.26^{***}	0.34^{***}	-0.22^{***}
MTY	-0.15^{*}	0.06	-0.24^{***}	0.20^{**}	0.29^{***}	1.00	0.18^{**}	0.96^{***}	-0.17^{**}
UMT	0.10	0.00	0.00	-0.08	0.26^{***}	0.18^{**}	1.00	0.44^{***}	0.00
TTY	-0.11	0.05	-0.22	0.16^{***}	0.34^{***}	0.96^{***}	0.44	1.00	-0.15^{*}
SG	0.12	-0.16^{**}	0.14	-0.12^{**}	-0.22^{*}	-0.17	0.00^{*}	-0.15	1.00

DE: Days to emergence; DF: Days to 50% flowering; DPM: Days to physiological maturity; SH (cm): Stem height (cm); SN: Stem $number^{-1}$; MTY: Marketable tuber yield (t ha^{-1}); UTY: Unmarketable tuber yield (t ha^{-1}); TTY: Total tuber yield (t ha^{-1}); SG: Specific gravity; CV: Coefficient variation

According to Solomon et al.(2019) and Solomon et al.(2014) indicated that increased number of stem plant^{-1} leads to increased plant height due to light availability and its effect on increased length and number of node. Solomon et al. (2019) also reported that tuber yield was significantly, and positively, correlated with average tuber weight, plant height, and total tuber number. Increasing numbers of stems and plant height allowed more light interception and likely an increase of production, and accumulation of, more carbon assimilation resulting in increased individual tuber size, weight and total tuber yield. All the above positive and strong association of growth characters implies those components are most important for potato yield improvement at south eastern parts of Ethiopia.

4. CONCLUSION

The significant effect of genotype by environment interaction for total yield indicated that there was variation among genotypes in performance and need to test all environment. From this study CIP 395037.107 was selected for possession of good yield as compared to standard check; which might be recommended for breeding purposes and official variety release.

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