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Evaluation of Advanced Potato (*Solanum tuberosum* L.) Clones for High Tuber yield and Processing Quality in Central Highlands of Ethiopia

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Abstract— *In this study selected potato clones were evaluated for acceptable processing tuber attributes with yield. The most important processed potato products in the country are French fries (chips), followed by crisps. The demand for these products has increased over the years and therefore require more effort to develop varieties with appropriate qualities for the rapidly developing industry. Therefore, the experiments were conducted from 2016 to 2019 at multiple locations in the central, northwestern and south-eastern regions of Ethiopia to evaluate the performance of seven (7) advanced potato genotypes breed at the International Potato Center (CIP) and three nationally released potato varieties for high tuber yield and processing qualities during the main cropping season, June to September. The experiment was laid out in a randomized complete block design with three replications in four locations over three years. The main objective of the experiments was to select high-yielding potato clones, with suitability for processing in four agro-ecological regions of the country. Data were collected on average tuber number, tuber weight, number and weight of marketable and unmarketable tubers,and total tuber yield. Tuber physicochemical properties, dry matter content (DM), specific gravity (SG), starch content (SC), and processing products after harvests were evaluated. Moreover, the frying suitability test (IBVL) and crispness/ texture/ for the product were evaluated. Analysis of variance was performed and treatment means were compared using the Duncan multiple range test. The results revealed that there were significant differences (p<0.05) among potato clones with respect to total and marketable tuber yields, dry matter content, and specific gravity. The highest total and marketable tuber yields were obtained from Holetta and Kulumsa, while Adet and Jeldu recorded the lowest. The growing season effect on clones marketable and total tuber yield, average tuber number and weight showed highly significant. The over locations mean for total and marketable tuber yield for CIP-398190.404 was 39.90 t/ha & 35.71 t/ha, respectively followed by CIP-391058.175 with 33.31 t/ha & 30.81 t/ha. Whereas, CIP-396034.103 gave 33.77t/ha and 28.84t/ha total tuber yield and marketable tuber yield, respectively. Tuber dry matter (DM) of 25.8, 24.3, and 25.7% was recorded, respectively. While, the specific gravity (SG) of 1.09, 1.08, and 1.09 g/cm^3 were obtained, respectively. The frying suitability test (IBVL) value showed that CIP-396034.103, (8.5) followed by CIP-398190.404, (7.5) and CIP-391058.175, (7.0). Among the evaluated clones, three cultivars had overall acceptable DM, SG, and frying suitability test (IBVL) for French fries and crisp processing. Thus, among the tested clones, CIP-391058.175 was registred as the first processing variety in Ethiopia.*

Keywords— ***Processing quality, dry matter, specific gravity, chips & crisp, frying suitability test.***

I. INTRODUCTION

Potato (*Solanum tuberosum* L.) the third most important food crop globally, is a major crop for both food security as well as income in many tropical countries. It is the most important non-grain crop and fourth most important crop in terms of global production (FAO, 2019). Global potato production has increased by about 20% since 1990, although production is still 50% below that of wheat, maize, and rice (FAO, 2019). It is the most important cultivated food crop with an overall production of 377 million tones of fresh weight in 2016 (FAOSTAT, 2017). It is the third most important food crop in the world after rice and wheat in terms of human consumption (FAOSTAT, 214). Consumption of fresh potatoes accounts for approximately two-thirds of the harvest, and around 1.3 billion people eat potatoes as a staple food (more than 50 kg per person per year), including regions of India and China (Devaux et al. 2014). According to (Birch et al., 2012), as world population levels are predicted to show the greatest rise in Africa in the coming decades, the increased contribution of potato to local food systems in this region is of considerable importance. Hence, enhancing the productivity of this root vegetable may be a key tool in fulfilling the nutritional requirements of the rising global population (Birch et al., 2012). Potato is not only a rich source of carbohydrates but also contains significant amounts of proteins, minerals, vitamins, micronutrients, and phytonutrients, including antioxidants as well as dietary fiber (Burlingame et al., 2009). It can provide more carbohydrates, proteins, minerals, and vitamins per unit area of land and time as compared to other potential food crops (Zaheer and Akhtar, 2016). In addition to being a raw marketable product, potato is widely used in industry for making processed food products, alcohol, starch, animal feed, and biofuel production Scott and Suarez, 2012; Liang and McDonald, 2014). Short crop duration and wide climatic adaptability have facilitated potato to spread across diverse geographical borders from its South American origin. Today, more than 3000 potato cultivars are widely distributed in more than 125 countries, particularly in temperate, subtropical, and tropical regions, covering a major economic share in the global agricultural market (Birch et al., 2012). For the last two decades, potato cultivation and utilization have also notably increased in developing countries such as Bangladesh, India, and China (Zaheer and Akhtar, 2016).

Potatoes are a precious source of food for many low-income people in both urban and rural areas. It can be consumed in different forms, such as boiled, roasted, French fried and chipped (Kibar, 2012). Potato contains practically all essential dietary constituents like carbohydrates, essential nutrients, proteins, vitamins, and minerals(Sriom et al., 2017). Even though the productivity of potato could reach up to 30 t ha^{-1} attainable yield and its productivity in Ethiopia is very low (Haverkort et al., 2012). These authors (Haverkort et al., 2012), also reported that currently, potatoes are cultivated on more than 0.3 million ha of land in the country, engaging more than 5 million smallholder farmers with an annual production of about 3.6 million tons (CSA, 2016). Even if there is a huge increment compared to the other crops grown in the highland areas during the same period of years, the potential attainable average yields of the potato crop on research and farmers' fields are 45 and 25 t ha^{-1}, respectively (Gebremedhin, 2013), while the current national average production is limited to about 14.1 tha^{-1}(CSA, 2019). There are many complicated reasons for this low actual yield of potato in the country. Soil fertility, lack of good quality seeds, unbalanced mineral nutrition, and inadequate application of fertilizers, pests and disease, irregularity of water supply and traditional irrigation schemes and schedules are the main reasons that account for the low productivity of potato (Bezabih and Mengistu, 2011).

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 potato has become common practice, especially in cities like Addis Ababa, Hawassa, Adama, Mekele, Dire Dawa, etc. In urban areas, it is also usually consumed mixed with other vegetables as a salad (Bezabih and Mengistu, 2011). Large-scale potato processing industries are under the process of establishment in Ethiopia. In large cities like Addis Ababa, it is common to see that hotels, restaurants, and cafes prepare homemade French fries (chips) and crisp from potatoes. Whenever urban consumers go out for recreation, they often prefer to go along French fries (chips) and crisp for snacks. Street vendors also prepare chips that are supplied to consumers at dusk. Meanwhile, the economic importance of potato manufacturing industries has not yet been attained, and quality potato varieties for processing have not been identified. Processing is the fastest growing sector in the world potato economy. The potato processing industry in many developing countries is also growing rapidly (FAO, 1995). The increase in consumer income levels, changing rural and urban infrastructure, lower potato prices, greater foreign investment, and increasing numbers of fast-food restaurants are the main factors increasing the demand for processed potatoes.

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, for instance, chips, growers should consider the market potential and quality characteristics as well as the ability for produce potatoes with a high specific gravity (Kimondo, 2007). Every factor that is a part of the environment has the potential to cause differential performance, which is associated with genotype X environment interaction in potatoes. The entire variable encountered in producing a crop can be collectively called the environment and every factor that is a part of the environment has the potential to cause differential performance that is associated with genotype and genotype to environment interaction in potatoes (Fehr, 1987). In addition, the available evidence indicates that the genetic factors inherent in a variety determine the cooking quality of potato within the range of influence exerted by the climate. Since the cooking qualities of potatoes needed by the processor for different types of food are so specific, it is essential to improve and select the varieties suitable for the different processed products (Irene et al., 1964).

In Ethiopia, the majority of potatoes produced are used for the preparation of different kinds of traditional foods. Recently, small-scale potato processors have been flourishing in cities and big towns. Potato processing for French fries (Chips) and crisps is becoming increasingly important as a snack food in Ethiopia. French fries and potato crisps are the most consumed industrially processed potato products in Ethiopia, especially in major urban centers. So far, a number of improved potato varieties have been released by different research centers and institutions. These varieties are widely grown in different growing environments of the country and are used for the preparation of traditional food types. In developing the varieties, much emphasis was given for adaptability, productivity per unit area, and late blight resistance, while less or no emphasis was given to physicochemical and processing attributes in relation to end uses. The most important concern for the potato chip industry is color, because if a desirable color is not obtained, the relative importance of the remaining traits is diminished. Quality traits important for cultivars used in potato chips manufacturing include high tuber shape, tuber eye depth, dry matter, low sugar, and free from defects (Dale and Mackay, 1994).

As the potato processing industry is emerging 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 (Rana and Pandey, 2007). This showed that the need to study advanced potato clones and released varieties whether they meet or not the demand for potato tuber qualities for a specific market and processed produce like Chips. This has urged to evaluate chips and crisps making the quality of potato clones and the released varieties in central highlands of Ethiopia. This helps to identify the varieties for processing quality and generating information that could be utilized as a yardstick in a variety of development for processing. Therefore, this study was conducted with the objectives to evaluate and select suitable potato clones that grows under different growing agro-ecologies for potato breeding purposes, with higher tuber yield, tolerant to late blight, especially targeting better processing qualities for chip and French fries purpose.

II. MATERIALS AND METHODS

2.1. Description of the Study Sites

The field experiment was carried out at four locations namely; Holetta, Jeldu, Adet, and Kulumsa which represent highland altitudes of potato growing areas of central highlands and Southeastern parts of Ethiopia. The experiment was conducted for three main cropping seasons (2016 - 2019) at all four locations. The study was conducted at Holetta agricultural research center (HARC). Holetta, which is located in the Oromia National Regional State and about 29 km far from Addis Ababa in West direction. The site, Holetta Agricultural Research Center, lies at 9° 00’ N latitude, 38° 30' E longitude and with an elevation of 2400 m.a.s.l. in central Ethiopia. The daily average minimum and maximum temperatures of the area were 6.42°C and 27.2°C, respectively, and the mean annual rainfall was 918.31 mm. The soil of the experimental site is predominantly Nitisols, which is characteristically reddish to brown. It has a soil pH of 5.24 and clay in texture with contents of 62.5% clay, 30.0% silt, and 7.5% sand. The soil has organic matter content of 2.18%, and total nitrogen, available phosphorus, and exchangeable potassium contents of 0.18%, 30.58 ppm, and 0.14 meq. 100 g^{-1} soils, respectively (Kidest et al., 2019), Jeldu sub-station of Holetta agricultural research center is situated at a distance of 72 km to the East of Ambo (Zonal town) and 115 Km West of Addis Ababa. The site is located at N 9º, 08’, 21”N 038º, 30’, 20”E and at altitude 2800 m.a.s.l. While Adet agricultural research center is located at 11º 16’ N, 37° 29’ E, at an altitude of 2240 m.a.s.l. Whereas Kulumsa at 8°,01′,07″ N and 39°,09′,32″E at an altitude of 2200 m.a. s. l.

2.2. Experimental treatment and design

A total of 10 potato genotypes were used for the experiment. The experiments were laid out as a Randomized Complete Block Design (RCBD) with three replications. Each plot was 3m x 3m ($9m^2$) wide consisting of four rows, which accommodated 10 plants per row and thus 40 plants per plot. The spacing between plots and adjacent replication was 1m. At each site, medium-sized (39-75g) (Lung'aho et al., 2007) and well-sprouted tubers were planted at the spacing of 75cm between ridges and 30cm between tubers. Fertilizer was applied as the recommendation made by Holetta Agricultural Research Centre, which Phosphorus and Nitrogen fertilizer were applied at the rate of 92kg P_2O_5 ha^{-1} and 110 kg N ha^{-1}, respectively. Nitrogen was applied in two splits, half at planting and half at the first ridging (45 days after planting). Potato plants were sprayed with Ridomil 80% WP at the rate of 2kg ha^{-1} diluted at the rate of 120 g per 20 liters water when the symptom observed on the first leaf to control late blight disease. All other cultural practices were applied according to Holetta Agricultural Research Centre recommendation. For data estimation, tubers were harvested from middle rows, leaving the plants growing in the two border rows as well as those growing at both ends of each row to avoid edge effect.

Data were collected on plant emergence, late blight incidence, plant height as well as a number of stem per plant during the vegetative growth stage, number of tubers per plant, tuber yield (t/ha), average tuber weight in gram (ATW), average tuber number per plant (ANT/p), and tuber physical characteristics like skin color, shape, eye depth, and flesh color were recorded. Quality parameters such as dry matter content and specific gravity were taken during harvesting. After maturity, the crop was dehaulmed two weeks before harvesting. Following harvest, the tubers were allowed to cure in a common dark store under ambient air conditions (17-22°C/ 84-92 % RH) for two weeks at the Horticulture research division of Holetta. The tubers were thereafter analyzed for physical-chemical characteristics and processed into French fries and crisps.

2.3. Determination of physical tuber characteristics

The physical tuber characteristics (shape, size, skin and flesh color, and eye depth), were determined according to the methods described by (Kabira and Lemaga, 2006; Abong'et al. 2009). In addition, tuber shape, size, and eye depth were analyzed by a method described by (Abong' et al., 2010c). Round tubers with shallow or medium eye depths and of size 40-60 mm in diameter were considered suitable for crisps processing while the round oval tubers of size ≤ 50 mm were considered suitable for French fries.

2.4. Determination of specific gravity and dry matter content

Specific gravity was determined in the raw tubers according to a weight underwater method as described by Ludwig (Ludwig, 1972). Tubers with a specific gravity of ≥ 1.070 were considered suitable for processing. For the determination of a dry matter, five whole tubers were randomly selected from each cultivar and cut into small slices (1-2 mm) and mixed thoroughly. Dry matter contents were then determined by drying triplicate 20 g samples at 80°C for 72 hr. in a forced-air oven. Tubers with dry matter contents ≥ 20 % were considered ideal for crisps and French fry processing.

2.5. Color and Texture measurements

It was measured using a standard color chart having scale ranging from grade 1 to 5 (1 = the lightest color (white to cream), 2 = light tan, 3 = dark tan, 4 = brown and 5 = dark brown, French fries (chip) and crisp color between grade 1 and 2 is commercially acceptable (Amoros et al., 2000; CIP, 2007).

2.6. Data analysis

The quantitative data were subjected to analysis of variance (ANOVA). The ANOVA was computed with SAS statistical software (9.2) (SAS 2009). The comparison of the mean performance of genotypes was done the significance of mean squares using Least Significant Difference (LSD).

III. RESULTS AND DISCUSSION

The ANOVA results of the study revealed that the evaluated clones were highly significant ($P< 0.05$) for growth performance, tuber yield, and quality traits except for average tuber weight. Plant height, average stems number, and average tuber number varied from 61.48 to 74.87 cm, 3.70 to 5.57, and 8.76 to 13.22 per plant, respectively (Table 1). The highest plant height was obtained from variety Gudanie (74.87cm) followed by Belete (72.86cm) and CIP-396034.103 (72.40cm) while the lowest plant height was observed for CIP-391046.14 (61.48cm). Relatively the highest average stems number was observed from variety Gudanie (5.57). On the other hand, the lowest average stems number was counted from variety, Belete (3.70). Moreover, the remaining genotypes were statistically similar. Addisu et al. (2013) reported that 26.7 to 99.0 cm for plant height and 3.8 to 9.7 for the number of stems per plant among 13 potato genotypes. The study by Rangare and Rangare (2017) indicated that 2.93 to 7.51 numbers of stem per plant among 44 potato genotypes. Similarly, Arslanoglu et al.,(2011) also reported plant height and numbers of stems per plant of 30.8 to 103.4 cm and 1.1 to 8.0, respectively among 146 potato genotypes. The average tuber weight ranges from 90.0 to 129.0 g/plant whereas marketable tuber number ranges from 106.75 to 160.16m^{-2}. The highest average tuber weight was recorded for Belete (129 g/plant) while the lowest average tuber weight was obtained by genotypes CIP-391046.14 (90 g/plant). The highest marketable tuber number recorded for Jalenie (160.16m^{-2})

whiles the lowest marketable tuber number counted for genotype CIP-391046.14 (106.75m^{-2}).

A stydy by Tesfaye et al. (2013) described highly significant differences among potato clones for average tuber number per hill and average tuber weight under Adet, Merawi, and Debretabor environments. The authors also reported highly significant differences among potato clones for average tuber number per hill and average tuber weight under Adet, Merawi, and Debretabor environments. Moreover, Getachew et al.(2016) reported 3.8 to 114.5g for average tuber weight for 24 potato genotypes evaluated in Bale highlands, South Eastern Ethiopia. Similarly,(Addisu et al., 2013; Haydar et al. 2007; Ozturk and Yildirim, 2014) also found significant variation among potato genotypes for the number of tuber per hill and average tuber weight.

Table 1: Mean of potato clones for processing at Holetta, Jeldu, Adet, and Kulumsa during 2017/18

No	Clones	PH (cm)	MSN/ plant	ATN /plant	ATW (g/plant)	MTN/m^2
1	CIP-381381.20	70.66^{abc}	4.23^{bc}	10.52^{b}	110.00	129.73^{bcd}
2	CIP-398180.289	64.42^{de}	4.24^{bc}	9.48^{bc}	119.00	114.56^{cd}
3	CIP-398190.89	68.37^{bcd}	4.85^{ab}	10.09^{bc}	97.00	127.51^{bcd}
4	CIP-398190.404	69.06^{abcd}	4.29^{bc}	10.29^{bc}	104.00	135.94^{bc}
5	CIP-391058.175	69.39^{abcd}	4.40^{bc}	11.11^{b}	104.00	138.74^{ab}
6	CIP-396034.103	72.40^{ab}	4.65^{b}	9.56^{bc}	113.00	122.42^{bcd}
7	CIP-391046.14	61.48^{e}	4.75^{b}	8.76^{c}	90.00	106.75^{d}
8	St.check (Belete)	72.86^{b}	3.70^{c}	10.61^{b}	129.00	134.4^{bc}
9	Gudanie	74.87^{a}	5.57^{a}	10.80^{b}	116.00	142.85^{ab}
10	Jalenie	65.76^{cde}	4.85^{ab}	13.22^{a}	106.00	160.16^{a}
	CV (%)	10.55	19.99	20.36	47.07	21.96
	P-Value	0.0005	0.0007	0.0005	NS	0.0021

Means followed by the same letters with in the same column are statistically non- significant at $p<0.05$ according to the least significant difference (LSD) test. CV (%) = coefficient of variation, PH=plant height, MSN= main stem number, ATN= average tuber number, ATW=average tuber Weight, MTN=marketable tuber number.

The combined analysis of variance for each location over growing seasons revealed that total tuber yield and marketable tuber yield had a highly significant ($P< 0.05$) difference. The studied potato genotypes had displayed a wide range of variation in total tuber yield that ranged from 25.41 to 39.89 t ha^{-1} with the mean performance of 31.46 t ha^{-1} (Table 2). The highest total tuber yield was recorded for Belete (39.89 t ha^{-1}) followed by Gudanie (36.19 t ha^{-1}). Potato genotypes, CIP-398190.404, CIP-398180.289, CIP-398190.89, CIP-396034.103, CIP-381381.20, and CIP-391058.175 gave total tuber yield of 34.32 t ha^{-1}, 33.01 t ha^{-1}, 32.18 t ha^{-1}, 31.60 t ha^{-1}, 31.41 t ha$^{-1,}$ and 31.00t ha^{-1}, respectively in descending order. However, the lowest total tuber yields were obtained from CIP-391046.14 (25.41 t ha^{-1}) and Jalenie (27.77 t ha^{-1}). Marketable tuber yield ranged from 20.27 to 33.81 t ha^{-1} with the mean performance of 26.88 t ha^{-1}. Similar study was conducted by (Rangare and Rangare, 2017) and reported the presence of significant variation among genotypes for total tuber yield, marketable tuber yield. Potato genotypes showed significant differences for internal quality traits (specific gravity, dry matter content of tubers) as presented in Table 2. The over locations mean for dry matter content (DM) and specific gravity (SG) revealed that all genotypes showed acceptable DM and SG for French fries and crips processing.

The genotypes varied concerning dry matter content and specific gravity which ranged from 19.45 to 21.92% while 1.073 to 1.082gcm^{-3}, respectively. Potato variety Belete had the highest dry matter content (21.92%) followed by genotype CIP-391058.175 (21.41%) while the highest specific gravity recorded for CIP-391058.175 (1.082 gcm^{-3}) and CIP-396034.103 (1.080 gcm^{-3}), respectively. Tuber specific gravity, which is a measure of dry matter content, is a critical processing quality trait. Dry matter of potato tubers and chip color is genetically controlled and influenced by environmental conditions during growing season and storage temperature (Kawchuk et al., 2008). Processing quality of potato tubers is determined by high dry matter, and low reducing sugar and phenol contents (Kadam et al., 1991; Abong' et al., 2009). High dry matter content increases chip yield, crispy-consistency, and reduces oil absorption during cooking (Pedreschi et al., 2005; Rommens et al., 2010). Low reducing sugars and phenol contents are required to avoid dark color and bitter taste of processed products, which negatively affect consumer acceptance (Wiltshire and Cobb, 1996).

Potato cultivars with high dry matter are required for the production of French fry (chips), and starch. According to study conducted by (Asmamaw et al., 2010; Elfinesh and Tekalign, 2011; Tesfaye et al., 2012; Ismail et al., 2015) the dry matter content and a specific gravity of tubers are significantly influenced by the interaction effect of growing environment and cultivars. Dry matter content is also the other critical character highly demanded by the processing industry. It is a measure of the tuber internal quality. Kirkman (2007) reported that a potato variety with dry matter content below 19.5% and 20% is not acceptable for French fries and chips, respectively. Similarly, a dry matter content of more than 25% is not suitable for French fries manufacturing. In addition, Wassu, (Wassu Mohammed, 2017 & 2016) described that highly significant differences among genotypes for internal tuber quality traits (dry matter content and specific gravity) tested under different agro-ecologies of eastern parts of the country. Moreover, Silva et al.(2014) described that specific gravity is an important trait, because it 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.

Table 2: Over locations means of processing clones at Holetta, Jeldu, Adet and Kulumsa during 2017/18

No	Clones	MTY (t/ha)	TTY (t/ha)	DM (%)	SG(g/cm^3)
1	CIP-381381.20	27.09^{bc}	31.41^{bcd}	19.97^{cd}	1.075^{cd}
2	CIP-398180.289	28.06^{abc}	33.01^{bc}	20.64^{abcd}	1.079^{bcd}
3	CIP-398190.89	25.66^{bcd}	32.18^{bc}	19.46^{d}	1.073^{d}
4	CIP-398190.404	29.10^{abc}	34.32^{ab}	20.08^{bcd}	1.076^{bcd}
5	CIP-391058.175	26.25^{bc}	31.00^{bcd}	21.41^{ab}	1.082^{ab}
6	CIP-396034.103	28.00^{abc}	31.60^{bc}	20.89^{abc}	1.080^{abc}
7	CIP-391046.14	20.27^{d}	25.41^{d}	20.09^{bcd}	1.076^{bcd}
8	St.ch(Belete)	33.81^{a}	39.89^{a}	21.92^{a}	1.074^{d}
9	Gudanie	30.87^{ab}	36.19^{ab}	19.63^{cd}	1.074^{cd}
10	Jalenie	23.61^{cd}	27.77^{cd}	19.45^{d}	1.075^{cd}
	CV (%)	26.36	23.59	1.43	0.63
	P-Value	0.0021	0.0014	0.0086	0.0028

Means followed by the same letters with in the same column are statistically non-significant at $p<0.05$ according to the least significant difference (LSD) test. CV (%) = coefficient of variation, MTY=marketable tuber yield, TTY= total tuber yield, DM= dry mater, SG=specific gravity.

The analysis of variance for 6 traits of 10 potato genotypes was presented in Table 3. The results revealed the presence of highly significant differences ($P< 0.01$) among potato genotypes for all traits. Plant height ranged from 45.77 to 64.57cm. The highest plant height recorded for genotype CIP-396034.103 (64.57cm) while the lowest plant height recorded for Jalenie (45.77cm). The average main stem number ranged from 3.03 to 5.12 whereas average tuber number ranges from 10.62 to 15.84 per hill. The average tuber weight ranges from 45.15 to 78.35

g/plant. The total tuber yield of the tested genotype ranges from 21.94 to 40.87 t ha^{-1}. The highest total tuber yield was recorded from Belete (40.87 t ha^{-1}) while the lowest total tuber yield was obtained from Jalenie (21.94 t ha^{-1}). Marketable tuber yield ranges from 20.34 to 36.57 t ha^{-1}. The highest marketable tuber yield recorded for (36.57 t ha^{-1}) while the lowest marketable tuber yield obtained from Jalenie (20.34 t ha^{-1}). The combined analysis of variance for each location over growing seasons revealed that all parameters were highly significant (P<0.01) among genotype, locations, and the interaction of genotype x locations (Table 3).

Table 3: Over location and years means of processing clones at Jeldu, Adet and Kulumsa from 2016-2018

No	Clones	PH (cm)	MSN /plant	ATN/ plant	ATW (g/plant)	MTY (t/ha)	TTY (t/ha)
1	CIP-381381.20	62.82^{ab}	3.40^{d}	10.92^{e}	68.90^{bc}	29.49^{cd}	32.24^{c}
2	CIP-398180.289	49.19^{d}	3.03^{d}	10.62^{ef}	73.96^{ab}	26.73^{e}	30.01^{d}
3	CIP-398190.89	60.83^{b}	4.79^{ab}	12.42^{cd}	67.75^{c}	33.02^{b}	35.59^{b}
4	CIP-398190.404	60.41^{b}	4.10^{bc}	11.88^{cde}	73.38^{abc}	35.71^{a}	39.90^{a}
5	CIP-391058.175	60.04^{b}	3.67^{cd}	11.81^{de}	69.45^{bc}	30.81^{c}	33.31^{c}
6	CIP-396034.103	64.57^{a}	4.53^{ab}	11.94^{cde}	60.42^{d}	28.84^{d}	33.77^{c}
7	CIP-391046.14	52.65^{c}	3.44^{cd}	14.14^{b}	54.51^{d}	26.08^{e}	29.87^{d}
8	St.check (Belete)	62.68^{ab}	3.04^{d}	12.95^{c}	78.35^{a}	36.57^{a}	40.87^{a}
9	Gudanie	60.27^{b}	5.12^{a}	15.84^{a}	46.17^{e}	28.83^{d}	32.24^{c}
10	Jalenie	45.77^{e}	3.41^{cd}	11.44d^{ef}	45.15^{e}	20.34^{f}	21.94^{e}
	LSD (0.05)	2.8364	0.7021	1.0993	5.9704	1.6346	1.7301
	Locations						
	Jeldu	47.27^{c}	3.51^{b}	9.60^{c}	65.07a	24.52^{c}	27.05^{c}
	Adet	60.28^{b}	3.61^{b}	13.20^{b}	58.56b	27.63^{b}	28.48^{b}
	Kulumsa	66.22^{a}	4.44^{a}	14.39^{a}	67.79a	36.78^{a}	43.38^{a}
	CV (%)	5.19	19.31	9.40	9.92	5.84	5.56
	LSD (0.05)	1.55	0.38	0.6021	3.2701	0.8953	0.9476
	P-value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
	R^2	0.96	0.79	0.92	0.89	0.97	0.98

Means followed by the same letters with in the same column are statistically non-significant at p<0.05 according to the least significant difference (LSD) test. CV (%) = coefficient of variation, PH=plant height, MSN= main stem number, ATN= average tuber number, ATW=average tuber weight, MTY=marketable tuber yield, TTY=total tuber yield.

The results of the study revealed that the evaluated clones are not statically significant as compared to standard check (Belete) but better than the early released varieties, Gudanie, and Jalenie for tuber yield. However, the over locations mean for total tuber yield and marketable tuber yield for CIP-398190.404 was 39.90 t ha-1 & 35.71 t ha-1, respectively followed by CIP-391058.175 with 33.31 tha-1 & 30.81tha-1 total tuber yield and marketable tuber yield, respectively whereas, CIP-396034.103 gave 33.77 tha-1 and 28.84 tha-1 total tuber yield and marketable tuber yield. The dry matter content (DMC) of 25.8%, 24.3%, and 25.7% were recorded, respectively. Dry matter content determines the suitability of genotype for processing purposes and thus affecting chips yields, texture, flavour, oil content and processing efficiencies (Luthra et al., 2018).

Similarly, specific gravity (SG) of 1.07 gcm^{-3}, 1.08 gcm^{-3} and 1.08 gcm^{-3} were obtained, respectively. Tuber dry matter is a varietal character; however, growing location, season, climatic conditions and cultural practices greatly affect the accumulation of dry matter in tubers, a dry matter content of more than 20% is considered ideal for making chips (Saran and Chhabra, 2014). A highly significant positive correlation was obtained between dry matter content and specific gravity proving that specific gravity is a true indicator of tuber dry matter content. Frying suitability test (IBVL) showed that CIP-396034.103, 8.5 followed by CIP-398190.404, 7.5, and CIP-391058.175, 7.0 in decreasing order (Table 4). The result from Senselet Food PLC showed that the tested genotype, CIP-398190.404,

CIP-391058.175 had a Short oval tuber shape with medium eye depth which is an indicator for suitability for French fry and Crisp. Moreover genotype, CIP-396034.103 had round tuber shape deep eye depth and 8.5 Frying suitability test was among the preferred genotypes for processing (Table 4). Thus, the above mentioned clones revealed that acceptable DM, SG, and Frying suitability test (IBVL) for processing and promoted these clones to be evaluated by the national variety release committee.

Table 4: Quality parameter for potato processing clones based on Senselet Food Processing PLC evaluation during 2018/2019

Cultivar	Shape	Skin color	Flesh color	Eye depth	Frying suitability test (IBVL)
CIP-381381.20	round	light pink	light yellow	deep	7.0
CIP-398180.289	round	yellow	light yellow	medium	7.5
CIP-398190.89	oval	light yellow	light yellow	medium	7.5
CIP-398190.404	Short oval	yellow	light yellow	medium	7.5
CIP-391058.175	Short oval	light yellow	light yellow	medium	7.0
CIP-396034.103	round	pink	Yellow	deep	8.5
CIP-391046.14	Short oval	yellow	light yellow	medium	7.5
Belete	Short oval	light yellow	light yellow	deep	7.0
Gudanie	Short oval	yellow	light yellow	medium	7.0
Dagim	Short oval	yellow	light yellow	medium	8.5

Source: Senselet Food Processing PLC during 2018/2019

According to Abbas et al.(2012) the acceptability of potatoes for processing as french fries is largely dependent on the quality of the end products. The processing industry is totally dependent on the quality parameters of tuber to satisfy the increasing demand of customers. The excellence of processed foodstuffs based on tubers is mainly subjected by quality characteristics like tuber shape, dry matter, specific gravity, reducing sugar, and color, appropriateness of these parameters is indispensable for evaluation of potato genotypes for processing industries (Zaman et al., 2016). Therefore, among the tested cultivars CIP-396034.103 and CIP-391058.175 were preferred by processing company, Senselet Food Processing PLC and after evaluation by national variety release committee approved that CIP-391058.175 clone for release and registred in Ethiopia as first processing potato in the country.

Tuber shape and eye depth: Tuber shape and eye depth of potatoes are important characteristics in influencing peeling and trimming efficiency during processing (Abong' et al., 2010). Tuber shape is a characteristic controlled by the genetic factors, and the environment may also affect it to some extent (Abbas et al., 2012). Most of the clones had Short oval shaped tubers and medium eyes depth except for three clones, the clone CIP-381381.20 with round shaped and deep eyes, clone CIP-398180.289 of round shaped with medium eyes depth and clone CIP-396034.103 with round shaped with deep eyes of tubers. Similar results presented by Li et al. (2005), who studied the inheritance and genetic mapping of tuber eye depth in potatoes, showed that the deep eye (Eyd) phenotype was found to be associated with round tubers (Ro) in most progeny clones. Based on shape, the cultivars with round shape have the potential to be processed to crisps that conformed to specifications (Abong' et al., 2010).

IV. CONCLUSION AND RECOMMENDATION

The significant differences for dry matter, specific gravity and yield and yield related traits are a sign of genetic variability for the traits which can be utilized by the breeding program to create new

varieties. There was great variation among the clones and the study was able to identify clones with good dry matter content, specific gravity and yield and yield components. The advanced potato clones evaluated in this study showed a differential response to tuber yield, processing quality, and dry matter content in the different environments. The main quality characteristics of interest to both French fries and crisp producers are tuber size and shape, flesh color, dry matter content, specific gravity, and reducing sugar content. A tuber physical characteristic like, tuber shape, eye depth and has been known to influence peeling and trimming efficiency during processing. Potato tubers that are round in shape are suitable for crisps processing for most processors especially due to ease of handling. From this study, potato clones with acceptable physical characteristics (tuber shape, eye depth, and tuber skin) were identified for processing among the evaluated clones. The round oval or pointed tubers, however, lend themselves easily for processing of French fries. Tuber size directly influences crisp and French fries size, which in turn influences post-frying handling. Larger tubers are ideal for French fries processing. However, larger tubers of more than 60 mm in diameter yield crisps which are fragile and break easily during packaging and transport. These finding were able to answer our objective of characterizing potato clones in order to identify those with desirable tuber processing attributes (dry matter content and specific gravity). It also showed a higher chance of selecting lones for high tuber yield with acceptable tuber quality. This encourages potato breeders to introduce potato genotypes and tests in the country to develop varieties suitable for the processing industry. From this study, potato clones CIP-398190.404, CIP-391058.175 and CIP-396034.103 were selected for possession of desirable processing tuber quality characterstics which can be recommended for breeding purposes and official variety release of the selected advanced clones after yield stability tests. Additional studies on these genotypes should focus on gene action, genotype by environment interaction of dry matter content and specific gravity.

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