Specific Gravity, Dry Matter Content, and Starch Content of Potato (*Solanum tuberosum* L.) Varieties Cultivated in Eastern Ethiopia

Wassu Mohammed*

School of Plant Sciences, P.O. Box 138, Haramaya University, Dire Dawa, Ethiopia

Abstract: Several farmers' and improved potato varieties are cultivated by farmers in the eastern highlands of Ethiopia. However, sufficient information is not available on tuber quality characteristics of the potato varieties. Therefore, experiments were conducted at three locations in the region, namely, Haramaya, Hirna and Arbarakatte in eastern Ethiopia during the 2012 to 2014 main cropping season to elucidate the internal tuber quality characteristics of 17 potato varieties and prepare a specific gravity conversion chart. The treatments consisted of 17 potato varieties (Araarsaa, Badhasa, Belete, Batte, Bubu, Bulle, Chala, Chiro, Gabbisa, Gera, Gorebela, Gudanie, Guasa, Jalenie, Jarso, Mara Charre and Zemen). The experiment at location was laid out as a randomized complete block design and replicated three times per treatment. The results revealed that tuber specific gravity (SG), dry matter (DM) and starch contents (SC) were significantly influenced by variety, location and year, while the interaction of the three factors significantly influenced SG and SC. All improved cultivars produced tubers with >1.085, >21% and > 14% of SG, DM and SC, respectively, and were found to be suitable for making French fries, chips and flakes. However, tubers of the local varieties had <1.07 gcm^2, < 20% and < 11% SG, DM and SC, respectively, and were found to be suitable for making whole boiled potatoes. The dendrogram constructed using Unweighted Pair-group Method with Arithmetic means separated the varieties into three clusters of which Cluster I with distinct Sub-group I consisted of eight improved varieties (Ararsa, Bule, Marachere, Badhasa, Challa, Jalanine, Gabisa and Zemen) and Sub-group II six improved cultivars (Bubu, Gera, Gorbella, Gudenine, Gusa and Chiro) , and Clusters II and III consisted of one improved variety (Belete) and two farmers' varieties (Batte and Jarso), respectively. The varieties found to be suitable for making processed potato products (French fries, etc) were grouped in the Sub-group I as they produced tubers with SG, DM and SC contents of acceptable standard for making such products while cultivars in Sub-group II and Belete (Cluster II) produced tubers with high SG, DM and SC contents that may produce too hard, dry and brittle French fries and chips. The correlation of specific gravity with dry matter and starch contents being perfect or near to perfect (r=0.962 to 1) across locations and seasons with high coefficient of determination (R^2=0.924 to 0.999). It could, thus, be concluded that it is appropriate to use specific gravity and the conversion chart produced from this tuber quality trait to estimate the other two traits (dry matter and starch contents) and determine the quality of tubers for processing.

Keywords: Coefficient of determination; Conversion chart; Correlation; Internal tuber quality.

1. Introduction

Potato global production has exceeded 376 million tonnes from over 19.3 million hectares (FAOSTAT, 2013). There is some estimate that the crop yield will have to double by 2050 to meet the demand of global food security. Importantly, potatoes are affordable, putting them within reach of the economically disadvantaged groups of people. Potato contains high protein-calorie ratio (17g protein: 1000 kcal) and yields more edible energy, protein and dry matter per unit area and time compared to cereals (Anderson *et al.,* 2010). In Ethiopia, potato has been considered as a strategic crop to enhance food and nutrition security. In 2013/14, potato was produced on 179,159 hectares of land with the total 1,612,006 and average of 9.1 tonnes of yield in the country. In East Hararghe, potato is a co-staple food (ORARI, 2007) and export commodity. It is approximately grown by 52,710 farmers with a total area of 2,507.12 hectares and average yield of 19.3 t ha^{-1} (CSA, 2014).

In Ethiopia, research for potato variety development and other agronomic managements began in 1975. The first potato variety was released in 1987. Ever since, 33 potato varieties have been developed and released in the country for production under different recommendation domains by research centers, Haramaya University and private companies (Baye and Gebremedhin, 2013; MoA, 2013). The National potato research effort has been in developing high yielding and late blight resistant varieties mainly for different kinds of traditional foods, but less emphasis has been given to processing products such as French fries, chips and others. However, small scale potato chips processors are flourishing in cities and big towns (Elfnesh *et al.*, 2011). Potato chips and French fries are commonly found in hotels, restaurants, supermarkets and small shops. In addition, the country has a potential in producing potatoes to supply large scale potato processing industries that might not be far from establishment. All varieties are not suitable for the production of processed products (Kabira and Berga, 2006). Therefore, it is necessary to evaluate the fitness of cultivars for the emerging economics of production until specific varieties are developed for specific end products.

*Corresponding Author. E-mail: wasmoha@yahoo.com

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Potato tubers quality is often referred to as external and internal quality. The internal quality is determined by many traits of which the most important are dry matter content, type and amount of starch, sugar, and protein content (Van Eck, 2007). High tuber specific gravity, dry matter and starch content are important for processing by enhancing chip yield, crispness and reduces oil uptake in fried products (Johnson *et al.*, 2010; Freitas *et al.*, 2012). Potato cultivars are significantly different in tuber specific gravity, dry matter content, and starch content (Hassanpanah *et al.*, 2011; Kaur and Aggarwal, 2014; Ismail *et al.*, 2015). Significant influence of environment and genotypes on specific gravity and tuber dry matter content was also reported (Elfnesh *et al.*, 2011; Tefaye *et al.*, 2013; Ismail *et al.*, 2015). Therefore, it is necessary to evaluate potato cultivars for internal tuber quality traits across locations and over seasons.

There is a close relationship among specific gravity, total solids and starch content and relationship has been developed by several workers among these traits (Johanson *et al.*, 1967; Fitzpatrick *et al.*, 1969; Willson and Lindsay, 1969; Verma *et al.*, 1972; Vakis, 1978; AOAC, 1980; Kleinkopf *et al.*, 1987; Dale and Mackay, 1994). Specific gravity conversion tables are available in other countries to be used by the potato processing industry (Houghland, 1966; Lulai and Orr, 1980; DEPI, 1995; USDA, 1997; Ezekiel *et al.*, 2003; Dinesh *et al.*, 2005). But these tables cannot be used in other countries since the relationship vary with the variety, location, season and the year of cultivation (Verma *et al.*, 1972). Therefore, it is necessary to evaluate potato cultivars across locations and seasons to determine their fitness for varied processing products and to prepare a conversion chart for specific gravity. In Ethiopia, limited reports are available for some of the released varieties regarding to potato tuber internal quality traits and processing aspects (Elfnesh *et al.*, 2011; Tefaye *et al.*, 2013). However, these studies did not include most of the cultivars under cultivation and were conducted only for one cropping season. Moreover, conversion charts for specific gravity, dry matter and starch contents have not been developed for cultivars in the country at large and in eastern Ethiopia in particular. Therefore, this research was conducted with the objectives: i) to evaluate potato cultivars for internal tuber quality traits, ii) to study the effect of growing locations and seasons on internal tuber quality traits; and iii) to establish the relationship among internal tuber quality traits and prepare conversion chart for specific gravity, dry matter and starch contents in eastern Ethiopia.

2. Materials and Methods

2.1. Description of the Study Sites

The field experiment was carried out at three locations namely; Haramaya, Hirna and Arberkete which represent mid and highland altitudes of potato growing areas of eastern Ethiopia. The experiment was conducted for two main cropping seasons (2012 and 2013) at all three locations. In addition, at Haramaya, potato cultivars were evaluated during the 2014 main cropping season. This made the total of seven environments considering one location and one cropping season as one environment.

Haramaya University research farm is located at 2020 meters above sea level, 9°41"N latitude and 42°03"E longitude. The area has a bimodal rainfall distribution with mean annual rainfall of 760 mm (Belay *et al.*, 1998). The long rainy season extends from June to October and accounts for about 45% of the total rainfall. The mean maximum temperature is 23.4^{0}C while the mean minimum annual temperature is 8.25^{0}C (Tekalign, 2011). The soil of the experimental site is a well-drained deep alluvial with a sub-soil stratified with loam and sandy loam. Hirna sub-station of Haramaya University is situated at a distance of about 134 km to the west of Haramaya. The site is located at 9 ^{o}12' North latitude, 41 ^{o}4'East longitude, and at an altitude of 1870 meters above sea level. The area receives mean annual rainfall ranging from 990 to 1010 mm. The average temperature of the area is 24^o C (Tekalign, 2011). The soil of Hirna is vertisol (HURC, 1996). Arbarakatte is located at a distance of about 171 km to the west of Haramaya. The site is located at 9 ^{o}14' North latitude, 41 ^{o}2'East longitude, and at an altitude of 2280 meters above sea level.

2.2. Experimental Materials

The experiment included 15 improved potato varieties which are under production and two farmers' varieties. These varieties were developed and released for different regions of Ethiopia by five Research Centers and Haramaya University (Table 1).

2.3. Experimental Design and Procedures

The experiment was laid out as a randomized complete block design (RCBD) with three replications in each location and season. Each potato variety was assigned to one plot in each replication and six rows with 12 plants. The gross plot size was 16.2 m^2 with 75 and 30 cm between rows and within plant spacing, respectively. The spacing between plots and replications was maintained at 1.5 m and 1 m, respectively. For measuring the specific gravity and dry matter content, tubers were harvested from plants in the four middle rows, leaving the plants growing in the two border rows as well as those growing at both ends of each row to avoid border effects.

The experimental fields were cultivated by a tractor (Haramaya and Hirna) to a depth of 25-30 cm and ridges were made by hand. Medium sized (39-75g) and well sprouted tubers were planted at the sides of ridges. Planting was at the end of June and first week of July during the main growing season after the rain commenced and when the soil was moist enough to support emergence. The planting depth was maintained at 10 cm. The whole recommended rate of phosphorus fertilizer (92 kg P_2O_5 ha^{-1}) was applied at planting in the form of Diammonium Phosphate. Nitrogen fertilizer was applied at the rate of 75 kg N ha^{-1} in the form of urea in two splits, half rate after full emergence (two weeks after planting) and half rate at the initiation of tubers.

2.4. Data Collection

Tuber dry matter content (%) was measured from five fresh tubers in each plot. The randomly taken tubers were weighed at harvest, sliced and dried in oven at 75°C until a constant weight was obtained and dry matter in percent was calculated according to Williams and Woodbury (1968) as follows.

$$\text{Dry matter (\%)} = \frac{Weight of\ sample after drying (g)}{Intial\ weight of\ sample (g)} \times 100 \quad (1)$$

Table 1. Studied potato varieties.

No.	Variety	Accession code	Year of release	Breeding center	Recommended altitude (m a.s.l.)
1	Araarsaa	CIP-90138.12	2006	Sinnana Research Center	2400-3350
2	Badhasa	AL-114	2001	Haramaya University	2400-3350
3	Belete	CIP-393371.58	2009	Holeta Research Center	1600-2800
4	Batte	Farmers' variety			
5	Bubu	CIP-384321-3	2011	Haramaya University	1700-2000
6	Bulle	CIP-387224-25	2005	Hwassa Research Center	1700-2700
7	Chala	CIP-387412-2	2005	Haramaya University	1700-2000
8	Chiro	AL-111	1998	Haramaya University	2700-3200
9	Gabbisa	CIP-3870-96-11	2005	Haramaya University	1700-2000
10	Gera	KP-90134.2	2003	Sheno Research Center	2700-3200
11	Gorebela	CIP-382173.12	2002	Sheno Research Center	1700-2400
12	Gudanie	CIP-386423.13	2006	Holeta Research Center	1600-2800
13	Guasa	CIP-384321.9	2002	Adet Research Center	2000-2800
14	Jalenie	CIP-37792-5	2002	Holeta Research Center	1600-2800
15	Jarso	Farmers' variety			
16	Mara Charre	CIP-389701-3	2005	Hwassa Research Center	1700-2700
17	Zemen	AL-105	2001	Haramaya University	1700-2000

Source: Plant Variety Release, Protection and Seed Quality Control Directorate, Crop Variety Register Issue No. 16, pp. 161-164 (MoA, 2013, June, Addis Abeba, Ethiopia); m a.s.l = meters above sea level

Specific gravity of tubers was measured using weight in air and weight in water method. Five kg tubers of all shapes and sizes were randomly taken from each plot and washed with water then weighed first in air and then in water. The specific gravity of tubers was calculated using the following formula (Kleinkopf *et al*, 1987).

$$\text{Specific gravity } (gcm^{-3}) = \frac{Weight in air}{Weight in air - Weight in water} \quad (2)$$

Total starch content (g/100g) was estimated from specific gravity. Starch (%) = 17.546 + 199.07 × (specific gravity-1.0988) (Talburt and Smith, 1959 as cited by Yildrim and Tokuşoğlu, 2005) where specific gravity was determined as indicated above by the weight in air and weight in water method.

In addition, dry matter and starch content in percent were calculated from the measured specific gravity and dry matter of tubers using different methods established by different researchers and institutions of other countries. The calculation was made by placing the measured tubers specific gravity or dry matter of each cultivar in the equation and the measured specific gravity also used to read and obtain the corresponding dry matter and starch contents in Canada (DEPI, 1995) and USA (USDA, 1997) specific gravity conversion chart. These methods are as follows:

i. Dry matter (%) = -214.9206 + 218.1852 (specific gravity) (Kleinkopf *et al.*, 1987)
ii. Dry matter (%) = 3.33+211 (specific gravity-1) (Willson and Lindsay, 1969)
iii. Starch content (%)=17.565 + 199.07 (specific gravity – 1.0988) (Von Scheele equations cited by Hassel *et al.*, 1997)
iv. Starch content (%) = 17.55 + 0.891 * (tuber dry weight% – 24.182) (AOAC, 1980).
v. Both dry matter and starch content (%) estimated from Canada specific gravity conversion table (DEPI, 1995)
vi. Both dry matter and starch content (%) estimated from USA specific gravity conversion chart (USDA, 1997)

2.5. Data Analysis

Data collected for specific gravity, dry matter and starch content were subjected to i) analysis of variance for each location and season to test the presence of significant differences among varieties in each location, ii) combined analysis of variance conducted for each location over cropping seasons/years, and iii) unbalanced general analysis of variance computed for seven environments considering the three seasons and locations. Homogeneity of error variances was tested using Bartlett's test for Haramaya site since the experiment was conducted for three cropping seasons while F-test was conducted for Hirna and Arbarakatte where varieties were evaluated for two cropping seasons. After the homogeneity of error variances was observed in all locations across cropping seasons, combined analysis of variance was conducted for each location over cropping seasons. Similarly, Bartlett's test was conducted for seven environments and heterogeneity of the error variances was evident for specific gravity and starch content. Therefore, cultivars were compared for pooled means for each location over seasons and other analyses (regression and correlation) were made the same though the homogeneity of error variances was observed for dry matter content. Mean separation was employed following the significance of mean squares using Least Significant Differences (LSD) at 5% probability.

Linear regression analysis was used to establish the relationship among specific gravity, dry matter and starch content of which specific gravity was considered as independent variable and other two traits as dependent (response) variables. Linear regression analysis was conducted for each location and season as well as pooled mean values of each variety at each location over seasons to understand the differences of the relationships among each location and season and each location over seasons. However, specific gravity conversion table was prepared on the regression equation computed in each location over seasons using pooled mean values of each variety at each location over seasons. The specific gravity conversion for each location was presented in table and the computed regression was presented in graph for each location. Correlation analysis was conducted among the measured data and estimated values (using different methods and regression equation) for specific gravity, dry matter and starch content to test whether the recorded data were in agreement or in contrast to the established relationship among these traits.

The genetic distance of varieties was estimated using Euclidean distance (ED) calculated from, i) the measured mean values of each trait for each variety in seven environments, ii) estimated tuber dry matter and starch contents of each variety using regression equation computed for each location and season, and iii) estimated tuber dry matter and starch contents of each variety using regression equation computed for each location over seasons after standardization (subtracting the mean value and dividing it by the standard deviation) as established by Sneath and Sokal, (1973) as follows:

$$EDjk = \sqrt{\sum_{i=1}^{n}(Xij - Xik)^{2}} \qquad (3)$$

Where: EDjk = distance between varieties j and k; xij and xik= tuber internal quality traits (specific gravity, dry matter and starch contents) mean values of the ith trait for varieties j and k, respectively; and n= number of traits used to calculate the distance.

The distance matrix from tuber internal quality traits was used to construct dendrograms based on the Unweighted Pair-group Method with Arithmetic means (UPGMA). The results of the cluster analysis were presented in the form of dendrogram.

3. Results

3.1. Analysis of Variance and Mean Performance of Varieties

Potato varieties showed significant differences for specific gravity, dry matter and starch content in all environments (at each location and growing season) (data not presented). The combined analysis of variance for each location over growing seasons revealed that tuber dry matter content was significantly influenced by variety and the interaction of variety x season at Haramaya while it was significantly influenced by variety and season at Hirna and Arbarakatte (Table 2). Specific gravity and starch content showed significant variations due to variety, growing season and interaction of variety x season at Haramaya but only due to variety and the interaction of variety x season at Hirna and variety and season at Arbarakatte. Mean squares from unbalanced combined analysis of variance over years and locations revealed that dry matter content was significantly influenced by variety, season, location, interactions of variety x location and location x season while starch content was significantly affected by all possible interactions(Table 3). Specific gravity was significantly influenced by variety, season and interaction effect of variety x season and variety x location x season.

Table 2. Mean squares from analysis of variance in three studied locations.

Location	Source of variation	Dry matter content (%)	Specific gravity	Starch content (g/100g)
Haramaya	Replication (2)	6.058	0.0000116	0.5149
	Variety (16)	40.191**	0.000780**	30.716**
	Season	4.245	0.0001867**	7.871**
	Variety x Season (32)	2.269**	0.0000538**	2.1184**
	Error (100)	2.178	0.0000146	0.5744
	CV (%)	6	0.4	5.1
Hirna	Replication (2)	0.498	0.00000683	1.175
	Variety (16)	26.503**	0.00032602**	12.025*
	Season (1)	63.961**	0.00005775	5.13
	Variety x Season (16)	2.778	0.00008344*	4.847**
	Error (66)	1.696	0.00003203	1.481
	CV (%)	5.60	0.50	8.3
Arbarakatte	Replication (2)	2.821	0.0000823	1.745
	Variety (16)	21.139**	0.00052976**	19.579**
	Season (1)	3.491*	0.00028872*	4.743*
	Variety x Season (16)	1.78	0.0000662	2.108
	Error (66)	0.749	0.0000302	1.441
	CV (%)	3.5	0.50	10.3

*Note: * and **, significant at P < 0.05 and P < 0.01, respectively. Numbers in parenthesis represented degree of freedom.*

Table 3. Mean squares from unbalanced combined analysis of variance in three studied locations.

Source of variation	df	Dry matter content (%)	Specific gravity	Starch content (g/100g)
Replication	2	0.456	0.00005058	1.085
Variety	16	80.765**	0.00132426**	55.031**
Location	2	51.237**	0.00003343	4.260*
Season	2	8.196*	0.00013145*	4.964*
Variety x Location	32	2.788*	0.00005739	2.555*
Variety x Season	32	2.211	0.00008097*	2.669*
Location x Season	2	35.758**	0.00008907	7.062*
Variety x Location x Season	32	2.229	0.00006724*	2.815**
Error	236	1.782	0.00003885	1.291
CV (%)		5.5	0.57	7.65

*Note: * and **, significant at P < 0.05 and P < 0.01, respectively. Numbers in parenthesis represented degree of freedom.*

Belete followed by Gera, Bubu and Gorebela had highest specific gravity, dry matter and starch content across locations and years though the order of varieties varied according to the rank differences across locations (Table 4). Belete produced tubers with >27% dry matter content at Hirna and Arbarakatte while Gera and Gorebela at Haramaya and Bubu at Arbarakatte produced tubers >26% dry matter content. Chirro and Chala also produced tubers with >25% dry matter content in all locations. None of the improved varieties produced tubers with <1.08 specific gravity and <14% starch content except Badhasa had <14% starch content at Haramaya and Hirna. On the other hand, the two farmers' varieties produced tubers with <1.07 specific gravity except Jarso at Hirna. The highest tubers dry matter content, specific gravity and starch content were observed at Haramaya (2014) and Arbarakatte (2012 and 2013), respectively.

Table 4. Mean specific gravity, dry matter and starch contents of 17 potato varieties in three locations.

Location	Haramaya			Hirna			Arbarakatte		
Variety	DM	SG	Starch	DM	SG	Starch	DM	SG	Starch
Ararsa	24.4^{efg}	1.085^{efg}	14.79^{efg}	21.81^{f}	1.082^{efg}	14.19^{efg}	23.26^{g}	1.083^{ef}	15.27^{cd}
Badhasa	24.23^{fg}	1.081^{h}	13.9^{h}	22.63^{ef}	1.076^{gh}	13.28^{gh}	23.58^{fg}	1.082^{ef}	14.76^{d}
Belete	26.63^{a}	1.095^{a}	16.72^{a}	27.18^{a}	1.096^{a}	16.97^{a}	27.14^{a}	1.099^{a}	17.58^{a}
Batte	19.88^{h}	1.064^{i}	10.59^{i}	19.12^{g}	1.068^{i}	11.79^{i}	20.99^{h}	1.067^{g}	11.46^{e}
Bubu	25.79^{a-d}	1.09^{bc}	15.86^{bc}	25.35^{b}	1.089^{bcd}	15.57^{a-e}	26.82^{ab}	1.095^{ab}	17.23^{a}b
Bulle	24.84^{d-g}	1.087^{def}	15.11^{def}	22.33^{ef}	1.084^{def}	14.53^{d-g}	23.86^{efg}	1.085^{def}	15.21^{cd}
Chala	25.7^{a-e}	1.084^{fgh}	14.52^{fgh}	24.26^{bcd}	1.085^{c-f}	14.78^{c-f}	25.53^{cd}	1.089^{bcd}	15.52^{bcd}
Chirro	25.93^{a-d}	1.092^{ab}	16.23^{ab}	24.49^{bcd}	1.088^{b-e}	13.55^{fgh}	25.16^{cd}	1.089^{bcd}	15.62^{bcd}
Gabbisa	23.5^{g}	1.088^{cde}	15.3^{cde}	23.83^{cde}	1.087^{b-f}	15.15^{b-e}	24.57^{def}	1.081^{f}	14.79^{d}
Gera	26.27^{abc}	1.09^{bc}	15.87^{bc}	25.55^{b}	1.091^{abc}	15.94^{abc}	25.84^{bc}	1.091^{bc}	15.64^{bcd}
Gorebela	26.56^{ab}	1.092^{ab}	16.21^{ab}	25.13^{bc}	1.092^{ab}	16.27^{ab}	25.52^{cd}	1.091^{bcd}	15.95^{a-d}
Gudanie	25.25^{a-f}	1.089^{bcd}	15.56^{bcd}	24.75^{bc}	1.088^{b-e}	15.45^{b-e}	25.81^{c}	1.088^{cde}	16.65^{abc}
Guasa	25.59^{a-f}	1.092^{ab}	16.07^{ab}	23.77^{cde}	1.091^{abc}	15.97^{abc}	25.96^{bc}	1.088^{cde}	15.78^{bcd}
Jalenie	24.87^{d-g}	1.083^{gh}	14.37^{gh}	23.05^{def}	1.081^{fg}	14.21^{efg}	25.41^{cd}	1.09^{bcd}	15.33^{cd}
Jarso	19.08^{h}	1.061^{i}	10.00^{i}	19.27^{g}	1.072^{hi}	12.19^{hi}	20.11^{h}	1.061^{g}	10.32^{e}
Mara Charre	25.21^{b-f}	1.084^{efg}	14.69^{efg}	22.34^{ef}	1.084^{def}	14.59^{c-g}	23.65^{efg}	1.081^{f}	16.05^{a-d}
Zemen	25.17^{c-f}	1.087^{cde}	15.29^{cde}	23.66^{cde}	1.088^{b-e}	15.77^{a-d}	24.58^{de}	1.086^{c-f}	15.01^{cd}
Mean	24.64	1.085	14.77	23.44	1.085	14.72	24.576	1.085	15.19
LSD (5%)	2.39	0.0062	1.228	2.123	0.0092	1.984	1.4202	0.009	2.54
Year									
2012	24.36	1.083^{a}	14.32^{b}	22.65^{b}	1.08421	14.49	24.76^{a}	1.084^{b}	15.4^{a}
2013	24.62	1.086^{b}	14.96^{a}	24.23^{a}	1.08572	14.94	24.39^{b}	1.087^{a}	14.97^{b}
2014	24.94	1.086^{b}	15.03^{a}	--------	--------	-------	--------	--------	-------
LSD (5%)	NS	0.0015	0.298	0.515	NS	NS	0.344	0.0022	0.41

Note: Means in each column with similar letter(s) are not significantly different each other. DM = dry matter content in percent, SG gcm² = specific gravity, Starch = starch content g/100g of fresh tuber weight and LSD (5%) = least significant difference at 5% probability.

The dendrogram constructed using Unweighted Pair-group Method with Arithmetic means (UPGMA) clearly divided the varieties in to three clusters of which the first Cluster consisted of 14 released varieties which was divided in to two sub-groups (Figure 1). The first Sub-group consisted of eight varieties released between 2001 to 2006. The mean tuber specific gravity, dry matter and starch content of these varieties were either equal or less than the mean values of varieties but most of these varieties performed higher than the mean of varieties for dry matter and starch content at Haramaya and Arberkete, respectively. These varieties relatively perform better at these two locations for specific gravity. The second Sub-group consisted of six varieties which included the very old variety Chiro released in 1998 to recently (in 2011) released variety Bubu. This group had mean values higher than the overall mean values of varieties for all traits in all locations, but they had much higher tuber dry matter content (≥25%) and specific gravity (≥1.09) at Haramaya. Belete was formed a solitary Cluster II with highest specific gravity (≥1.096), dry matter (>27%) and starch content (>16.72%) except specific gravity of 1.095 and dry matter content of 26.63% at Haramaya. The third Cluster consisted of the two farmers' varieties (Batte and Jarso) which had <1.07, <20%, and <11% specific gravity, dry matter and starch content, respectively, in all locations, but these varieties had 1.07 and 11% of specific gravity and starch content, respectively, at Hirna and 20% dry matter content at Arberkete for different seasons.

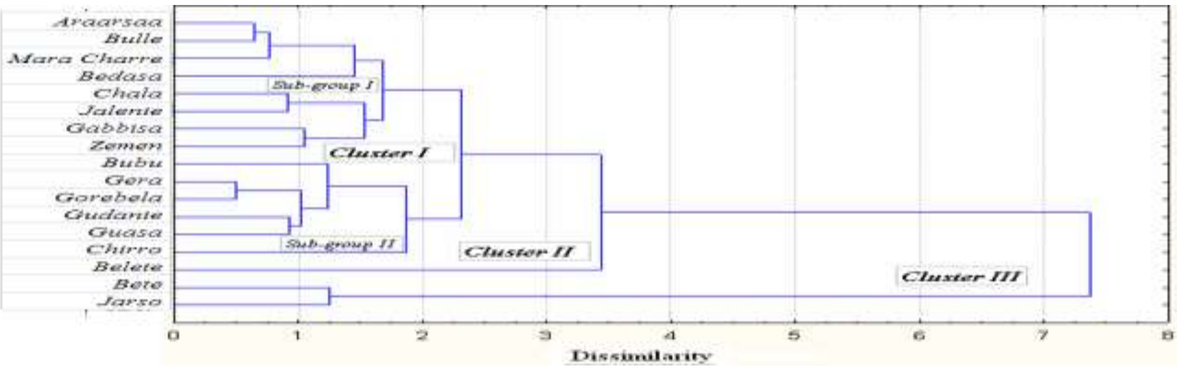

Figure 1. Dendrogram generated based on UPGMA clustering method depicting relationship among 17 potato varieties based on tuber specific gravity, dry matter and starch contents over years at three locations.

3.2. Relationship among Internal Tuber Quality Traits and Conversion Chart

The regression equations for each location and cropping season and pooled means over years for each location are presented in Table 5. The highest coefficient of determination ($R^2 \geq 0.924$) and correlation ($r \geq 0.962$) were computed for the regression of specific gravity, starch and dry matter contents for all locations in each year. However, regression computed on the basis of pooled means over years for each location showed that both coefficient of determination and correlation values were ≥ 0.99, ≥0.96 and ≥0.97 for Haramaya, Hirna and Arbarakatte, respectively. The graphic presentation of regression computed on the basis of pooled means over years for Haramaya, Hirna and Arbarakatte are presented in Figure 2, 3 and 4, respectively.

Table 5. Regression equation, coefficient of determination (R^2) and correlation of separate years and pooled mean.

Location	Year	Regression equation	R^2	Correlation (r)
		DM=-171.2307+180.6728 x SG	0.937	0.968
	2012	Starch=-199.7252+197.7151 x SG	0.999	0.999
		DM=-242.9437+246.4027 x SG	0.976	0.988
Haramaya	2013	Starch=-202.1383+199.9253 x SG	0.999	0.999
		DM=-260.2067+262.5102 x SG	0.986	0.993
	2014	Starch=-203.0845+200.8024 x SG	0.999	0.999
Pooled means over three years		DM=-222.2202+227.5344 x SG	0.992	0.996
		Starch=-201.7442+199.5626 x SG	0.999	0.999
		DM=-289.8848+288.2386 x SG	0.95	0.975
	2012	Starch=-208.3541+205.5233 x SG	0.984	0.992
Hirna		DM=-229.6209+233.7771 x SG	0.932	0.965
	2013	Starch=-202.199+199.9677 x SG	0.999	1.00
Pooled means over two years		DM=-278.0942+277.9138 x SG	0.964	0.982
		Starch=-189.9193+188.6054 x SG	0.978	0.989
		DM=-154.9683+165.8926 x SG	0.974	0.987
	2012	Starch=-176.3201+176.960 x SG	0.924	0.962
Arbarakatte		DM=-220.4252+225.2465 x SG	0.968	0.984
	2013	Starch=-188.4728+187.126 x SG	0.959	0.979
Pooled means over two years		DM=-192.1592+199.745 x SG	0.982	0.991
		Starch=-192.189+191.5153 x SG	0.976	0.988

Note: Correlation (r) = correlation coefficient, R^2 = coefficient of determination, DM = dry matter content, SG = specific gravity and Starch = starch content.

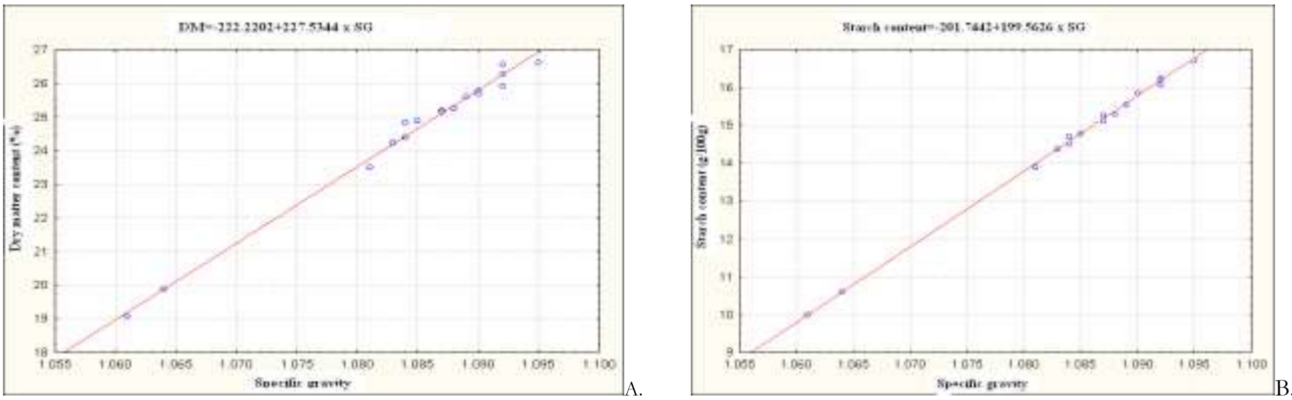

Figure 2. Linear regression of tuber specific gravity on A). Dry matter (DM) and B). Starch contents of 17 potato varieties with equation of best-fit line on the basis three years mean values at Haramaya.

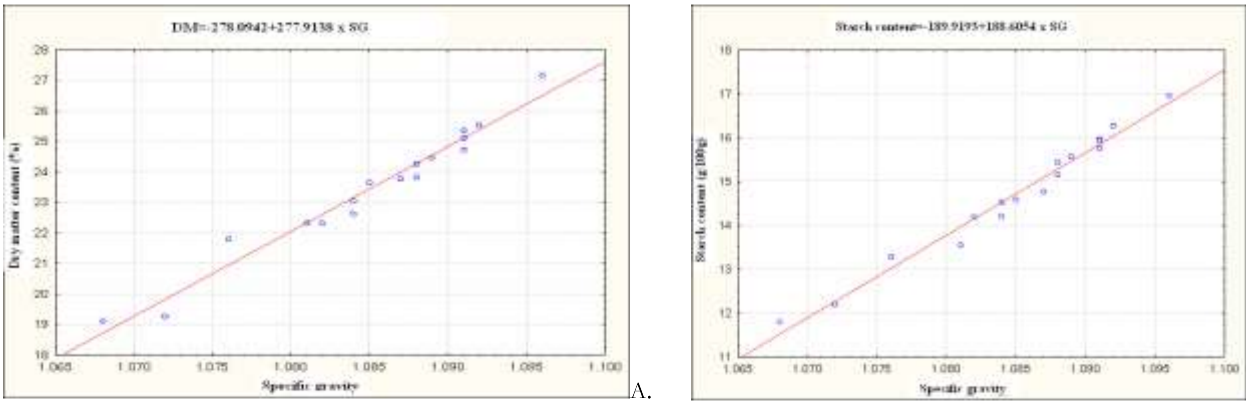

Figure 3. Linear regression of tuber specific gravity on A). Dry matter (DM) and B). Starch contents of 17 potato varieties with equation of best-fit line on the basis two years mean values at Hirna.

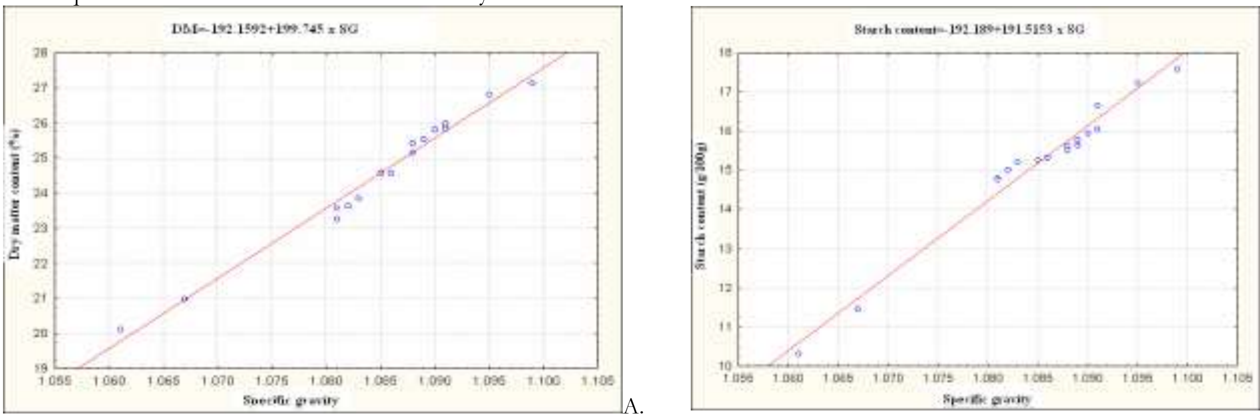

Figure 4. Linear regression of tuber specific gravity on A). Dry matter (DM) and B). Starch contents of 17 potato varieties with equation of best-fit line on the basis two years mean values at Arberkete

A specific gravity conversion chart is presented in Table 6. The dry matter and starch contents were 18.97 and 9.79%, respectively, for the lowest specific gravity of 1.06 at Haramaya, while the values were 16.49% (dry matter content) and 10% (starch content) at Hirna and 19.57 (dry matter content) and 10.82% (starch content) at Arberkete. Similarly, 28.09% (dry matter) and 17.79% (starch content) were computed for the highest specific gravity of 1.001 at Haramaya, while it was computed 27.64 (dry matter content) and 17.57% (starch content) at Hirna and 27.58 (dry matter content) and 18.50% (starch content) at Arberkete.

3.3. Correlation among the Observed and Estimated Internal Tuber Quality Traits

The correlation was highly significant among the observed (measured) and estimated (using different methods) tubers specific gravity, dry matter and starch contents. In most cases the correlation was perfect (r = 1.00) or near to perfect (r = 0.97 to 0.99) (Table 7). The measured tubers specific gravity showed perfect or near to perfect correlations with all calculated and estimated dry matter and starch contents except the correlations with measured dry matter content and estimated from regression equation and estimated starch content using AOAC (1980) method (r = 0.91 to 0.96). On the other hand, the observed dry matter content showed perfect or near to perfect correlations (r = 1.00 & r = 0.99) only with estimated dry matter and starch content using regression equation and AOAC (1980) methods, respectively. The measured dry matter content had correlation coefficient of r = 0.94 & r = 0.95 with estimated dry matter and starch contents from all other methods. As compared to measured dry matter content, the observed starch content had higher correlation coefficients (r $\geq$0.97) with observed and estimated specific gravity, dry matter and starch contents except for the correlation with the estimated dry matter and starch content from regression equation and AOAC (1980), respectively

Table 6. Conversion of specific gravity to dry matter and starch content for three locations calculated from regression equation on the basis of pooled means.

Location	Haramaya		Hirna		Arbarakatte	
SG (gcm²)	DM (%)	Starch (%)	DM (%)	Starch (%)	DM (%)	Starch (%)
1.060	18.97	9.79	16.49	10.00	19.57	10.82
1.061	19.19	9.99	16.77	10.19	19.77	11.01
1.062	19.42	10.19	17.05	10.38	19.97	11.20
1.063	19.65	10.39	17.33	10.57	20.17	11.39
1.064	19.88	10.59	17.61	10.76	20.37	11.58
1.065	20.10	10.79	17.88	10.95	20.57	11.77
1.066	20.33	10.99	18.16	11.13	20.77	11.97
1.067	20.56	11.19	18.44	11.32	20.97	12.16
1.068	20.79	11.39	18.72	11.51	21.17	12.35
1.069	21.01	11.59	19.00	11.70	21.37	12.54
1.070	21.24	11.79	19.27	11.89	21.57	12.73
1.071	21.47	11.99	19.55	12.08	21.77	12.92
1.072	21.70	12.19	19.83	12.27	21.97	13.12
1.073	21.92	12.39	20.11	12.45	22.17	13.31
1.074	22.15	12.59	20.39	12.64	22.37	13.50
1.075	22.38	12.79	20.66	12.83	22.57	13.69
1.076	22.61	12.99	20.94	13.02	22.77	13.88
1.077	22.83	13.18	21.22	13.21	22.97	14.07
1.078	23.06	13.38	21.50	13.40	23.17	14.26
1.079	23.29	13.58	21.77	13.59	23.37	14.46
1.080	23.52	13.78	22.05	13.77	23.57	14.65
1.081	23.74	13.98	22.33	13.96	23.77	14.84
1.082	23.97	14.18	22.61	14.15	23.96	15.03
1.083	24.20	14.38	22.89	14.34	24.16	15.22
1.084	24.43	14.58	23.16	14.53	24.36	15.41
1.085	24.65	14.78	23.44	14.72	24.56	15.61
1.086	24.88	14.98	23.72	14.91	24.76	15.80
1.087	25.11	15.18	24.00	15.09	24.96	15.99
1.088	25.34	15.38	24.28	15.28	25.16	16.18
1.089	25.56	15.58	24.55	15.47	25.36	16.37
1.090	25.79	15.78	24.83	15.66	25.56	16.56
1.091	26.02	15.98	25.11	15.85	25.76	16.75
1.092	26.25	16.18	25.39	16.04	25.96	16.95
1.093	26.47	16.38	25.67	16.23	26.16	17.14
1.094	26.70	16.58	25.94	16.42	26.36	17.33
1.095	26.93	16.78	26.22	16.60	26.56	17.52
1.096	27.16	16.98	26.50	16.79	26.76	17.71
1.097	27.39	17.18	26.78	16.98	26.96	17.90
1.098	27.61	17.38	27.06	17.17	27.16	18.09
1.099	27.84	17.58	27.33	17.36	27.36	18.29
1.100	28.07	17.77	27.61	17.55	27.56	18.48
1.1001	28.09	17.79	27.64	17.57	27.58	18.50

Note: SG (gcm²) = specific gravity, DM (%) = dry matter content and Starch (%) =starch content.

Table 7. Correlation coefficient among the measured and estimated specific gravity, dry matter and starch contents computed for each location and cropping season (above diagonal) and pooled means of three locations over years (below diagonal) (2012-2014)

	OSG	ODM	OSTAR	CDM	CSTAR	WDM FSG	KlDM FSG	DEPI DMFSG	DEPI STAR	VSSTAR	USADDM	AOACST
OSG		0.91**	0.97**	0.96**	0.98**	1.00**	1.00**	1.00**	1.00**	1.00**	0.99**	0.91**
ODM	0.94**		0.93**	0.95**	0.91**	0.91**	0.91**	0.91**	0.91**	0.91**	0.92**	1.00**
OSTAR	0.98**	0.95**		0.95**	0.97**	0.97**	0.97**	0.97**	0.97**	0.97**	0.96**	0.93**
CDM	0.95**	0.99**	0.96**		0.96**	0.96**	0.96**	0.96**	0.96**	0.96**	0.96**	0.95**
CSTAR	0.97**	0.95**	0.99**	0.96**		0.98**	0.98**	0.98**	0.98**	0.98**	0.97**	0.91**
WDMFSG	1.00**	0.94**	0.98**	0.95**	0.97**		1.00**	1.00**	1.00**	1.00**	0.99**	0.91**
KlDMFSG	1.00**	0.94**	0.98**	0.95**	0.97**	1.00**		1.00**	1.00**	1.00**	0.99**	0.91**
DEPI DMFSG	1.00**	0.95**	0.99**	0.95**	0.97**	1.00**	1.00**		1.00**	1.00**	0.99**	0.91**
DEPI STAR	1.00**	0.94**	0.99**	0.95**	0.97**	1.00**	1.00**	1.00**		1.00**	0.99**	0.91**
VSSTAR	1.00**	0.94**	0.98**	0.95**	0.97**	1.00**	1.00**	1.00**	1.00**		0.99**	0.91**
USADDM	1.00**	0.94**	0.98**	0.95**	0.97**	1.00**	1.00**	1.00**	1.00**	1.00**		0.92**
AOACST	0.94**	1.00**	0.95**	0.99**	0.95**	0.94**	0.94**	0.95**	0.94**	0.94**	0.94**	

*Note: **, significant at P < 0.01 probability. OSG = observed specific gravity, ODM = observed dry matter content, OSTAR = observed starch matter content, CDM = calculated dry matter content on the basis of regression equation, CSTAR = calculated starch content on the basis of regression equation, WDMFSG = estimated dry matter content from specific gravity using Willson and Lindsay (1969) method, KlDMFSG = estimated dry matter content from specific gravity using Kleinkopf et al. (1987) method, DEPI DMFSG = estimated dry matter content from specific gravity using specific conversion table of Department of Environment and Primary Industries of Canada (1995), DEPI STAR = estimated starch content from specific gravity using specific conversion table of Department of Environment and Primary Industries of Canada (1995), VSSTAR = estimated starch content from observed specific gravity using Von Scheele equations (cited by Hassel et al., 1997), USADDM = estimated dry matter content from observed specific gravity using specific gravity conversion chart of United States Agriculture Standard (USDA, 1997), AOACST = estimated starch content from observed dry matter content using official methods of analysis, Association of Official Analytical (AOAC, 1980).*

4. Discussion

The presence of wide variations among varieties for tuber specific gravity, dry matter and starch contents indicated the genetic factor was important to influence the tuber internal quality traits. The observed differences are a good opportunity for the producers to select the varieties for production that fit the market demand. Many other researchers also reported the presence of significant differences among potato cultivars for these tuber quality traits (Elfnesh *et al*., 2011; Hassanpanah *et al*., 2011; Tesfaye *et al*., 2013; Kaur and Aggarwal, 2014; Ismail *et al*., 2015). These traits were also significantly influenced by growing season and location. The influence of growing location on starch content in dry matter was reported (Dorota *et al*., 2011; Hassanpanah *et al*., 2011; Kaur and Aggarwal, 2014). Specific gravity and tuber dry matter content are influenced by both the environment and cultivars (Elfnesh *et al*., 2011; Ismail *et al*., 2015). However, the interaction of variety x location x season was significantly influenced specific gravity and starch content indicating the unstable expression of these traits in different varieties across locations and seasons. These quality traits are genetically controlled and also influenced with growing locations and seasons (Dorota *et al*., 2011; Hassanpanah *et al*., 2011; Kaur and Aggarwal, 2014). The result suggested the importance of testing potato varieties across locations and seasons to identify wide adaptable varieties that could produce tubers with uniform specific gravity and starch content in all environments since it benefit producers, processors and consumers.

All improved varieties produced tubers ≥1.08 and ≥23% specific gravity and dry matter content, respectively, in all locations and growing seasons except two varieties at two locations. On the other hand, the farmers' varieties had tubers with low values of <1.07 and <20% specific gravity and dry matter content, respectively. Tesfaye *et al.* (2013) reported dry matter content ranged from 17.05 to 29.88% for 25 potato genotypes studied at three locations of northwestern Ethiopia. Elfnesh *et al.* (2011) also reported 20.33 to 27.33% and 1.078 to 1.110 gcm^{-3} dry matter content and specific gravity, respectively, for five improved potato varieties tested at three locations in eastern Ethiopia. Specific gravity values considered as low (<1.077) intermediate (between 1.077 and 1.086) and high (>1.086) (Fitzpatrick *et al*., 1969). Potato cultivars with a dry matter content of 20% or higher are the most preferred for processed products (Kirkman, 2007). Kabira and Berga, (2006) suggested a dry matter content of 20 to 24% are ideal for making French fries while those with up to 24% for preparing crisps. They suggested also, potato tubers should have a specific gravity value of more than 1.080 and those with less than 1.070 are generally unacceptable for processing. This suggested the evaluated potato varieties were suitable for processing but farmers' varieties were not suitable for processing to French fries and chips.

The eight varieties (Ararsa, Bule, Marachere, Badhasa, Chala, Jalenine, Gabisa and Zemen) included in the first Sub-group of Cluster I had with mean tuber starch content of 14.56 to 15.24% whereas the six varieties (Bubu, Gera, Gorbella, Gudenine, Gusa and Chiro) in the second Sub-group had a mean starch content ≥15.46%. Belete formed solitary Cluster II had highest mean values up 17.58% of tuber starch content while farmers' varieties in Cluster III had lowest mean values of <12%. Tesfaye *et al.* (2013) reported starch content ranged between 10.44 and 18.51% for 25 potato genotypes that Betete had the highest tuber starch content. Starch is of special importance for the nutritional value ranges between 15-20% (Schafer-Pregl *et al*., 1998), important role in the cooking quality (Binner et al., 2000), starch production in starch processing industries (Liu *et al.,* 2003) and healthy food processing and consumption in relation to moderating blood glucose levels. Esendal (1990) suggested three groups: the highest starch content (>19.0%, mashing), high starch content (between 16.0 and 19.0%, roasting), intermediate starch content (between 13.0 and 15.9%, cooking or roasting), and low starch content (up to 12.0%, boiling). In general, potato varieties with a starch content of 13% and above are the most preferred for processed products (Kirkman, 2007). All improved varieties could be grouped under intermediate starch content fit for processed products either for cooking or roasting while Belete with high starch content for roasting and farmers' varieties with low starch content for boiling.

Starch concentration represents the dry matter content of potatoes (Hogy and Fangmeier, 2009). Since starch content has direct influence on technological quality, especially with regard to the texture of the processed products. High dry matter content increases chip yield, crispy consistency, and reduces oil absorption during cooking (Rommens *et al*., 2010). However, tubers with very high dry matter content produces too hard and dry French fries and the crisps will be too brittle. Potatoes with a dry matter content of 20 to 24% are preferred for French fries 22 to 24 for chips and >21% are preferred for flakes production (NIVAA, 2002). In this regard, the eight potato varieties under Cluster I, Sub-group I might serve for all purpose (French fries, chips and flakes) while the six varieties in same cluster in Sub-group II might be used for flakes production. Varieties in Sub-group II and more likely Belete may not serve for both French fries and chips because the products may have a higher chance to be too hard, dry and brittle due to tubers high dry matter content. The high tuber starch content of these varieties may result cell separation, reduced cohesiveness and softening during cooking (Binner *et al*., 2000) and may not preferred by diabetic patients. In this regard the two farmers' varieties may be preferred as producing healthy food due to their low starch content. Potato due to its high starch content mainly carbohydrate thought to contribute to some health problems such as diabetes and weight gain (Cordain, 2005; Mozaffarian *et al.*, 2011). Studies showed variability among potato genotypes for glycemic index values (Henry *et al.*, 2005; Parada and Aguilera, 2009). The waxy potatoes are with high moisture and low starch content and had medium glycemic index and the floury potatoes are high in starch and had high glycemic index (Henry *et al.*, 2005). Glycemic index is a measure of foods ability to affect human blood sugar levels. Foods with low glycemic index values are considered healthy food choices since they have the innate property of moderating blood glucose levels, while foods with a high value are considered to be the opposite (Jenkins *et al.*, 1981).

The relationship of specific gravity with tuber dry matter and starch contents was linear with high coefficient of determination and high positive correlation. The relationship was differing from location to location and season to season in the same location. However, the measured specific gravity showed perfect or near to perfect correlations with the estimated tuber dry matter and starch contents from regression equation. The relationship between specific gravity dry matter and starch contents of potatoes has been developed by several workers and associations (Johanson *et al.*, 1967; Fitzpatrick *et al.*, 1969; Willson and Lindsay, 1969; Verma *et al.*, 1972; Vakis, 1978; AOAC, 1980; Kleinkopf *et al.*, 1987; Dale and Mackay, 1994; Hassel *et al.*, 1997). The relationship among internal tuber quality traits has been found to vary with the variety, location, season and the year of cultivation (Verma *et al.*, 1972). On the other hand, the correlation of measured and estimated dry matter content with specific gravity and tuber starch content had lower coefficient values. This suggested measuring specific gravity and estimating starch content is preferred than estimating starch content from measured dry matter content. Tekalign and Hammaes (2005) reported the positive and significant correlation of tuber dry matter content and specific gravity and suggested specific gravity as a true indicator of the amount of tuber dry mater.

Specific gravity of potatoes is commonly used by the potato processing industry as a tool for quick estimation of dry matter content. The preparation specific conversion charts need to test genetically different potato genotypes at different locations and seasons. Johanson *et al.* (1967) suggested the importance of testing varieties for a few years under local conditions and to select wide adaptable varieties with the same specific gravity when grown across environments. Many authors reported the significant influence of growing season and location other than genotype on specific gravity and the two traits to be converted (Dorota *et al.*, 2011; Elfnesh *et al.*, 2011; Hassanpanah *et al.*, 2011; Kaur and Aggarwal, 2014; Ismail *et al.*, 2015). The prepared conversion chart for specific gravity was: i) the result of testing considerable number of potato varieties at representative potato growing areas of eastern Ethiopia for a couple of years, ii) it was observed positive and highly significant correlations of the measured specific gravity with the measured dry matter and starch contents, iii) most importantly, it was observed perfect or near to perfect correlations of the measured specific gravity with the estimated dry matter and starch contents using regression equation, and iv) it was also observed perfect or near to perfect correlations of the measured specific gravity with the estimated dry matter and starch contents with several methods. These could allow recommending the importance of measuring specific gravity and using the prepared specific gravity conversion chart as reliable indicator of tuber quality traits of the tested varieties and other potato genotypes in eastern Ethiopia.

5. Conclusion

The research results suggested the importance of evaluating varieties for internal tuber quality traits (specific gravity, dry matter and starch content) across representative locations of growing region over seasons. Because the observed significant influence of variety x location x season interaction on these traits make difficult to predict the tuber quality of potato varieties by testing them in one location over seasons. This also suggested the important of identifying wide adaptable (stable) varieties that produce tubers with uniform specific gravity and starch content throughout the production areas of the region that benefit producers, processors and end consumers. Though, the varieties were developed for high tuber yield, all the improved varieties produced tubers above the minimum requirements to fit different processing products (French fries, chips flakes etc.). However, some varieties produced tubers with high dry matter and starch content that might not be preferred for French fries and chips, because the products may have a higher chance to be too hard, dry and brittle. The farmers' potato varieties might be preferred to be used for making whole boiling tubers but not for making French fries and chips due to the low starch and high moisture contents of the tubers.

The research also suggested that measuring specific gravity of tubers is most appropriate to determine the quality of tubers. The prepared specific gravity conversion chart can be used as indicator of tuber dry matter and starch contents of potato genotypes and thereby to determine the internal quality of tubers for processing in eastern Ethiopia. From the research results it is possible to make conclusion and recommendation such as: i) it is necessary to develop wide adaptable varieties in the country that produce tubers with the same specific gravity through evaluation of varieties across major potato growing regions of the country, ii) use of specific gravity than dry matter content as good indicator of internal quality of tubers for processing, iii) it is necessary to prepare specific gravity conversion chart in the country at least for major potato growing regions of representative locations to be used by processors, other consumers and researchers, and iv) it is necessary to evaluate the varieties further for other physical tuber quality and quality of processed products to identify which variety(ies) fit to which processing to produce healthy food. These could not be accomplished with separate efforts of researchers at different research centers rather it will be successful with the coordinated joint efforts of potato researchers in the country.

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