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Yield and yield components of CIP advanced potato clones under Rwandan agro-ecologies

Rukundo Placide[1], Ndacyayisenga Theophile[1], Ntizo Senkesha[1], Kirimi Sindi[2], and Nshimiyima Jean Claude[2]

[1] Potato Sub-program, Rwanda Agriculture and Animal Resources Development Board (RAB), P.O. Box 5016 Kigali
[2] International potato center (CIP), Kacyiru Road St. 563, plot No 1490, Kigali, Rwanda.
[3] International Potato Center (CIP), Sub-Saharan African Region, ILRI Campus, Old Naivasha Road, Box 25171-00603, Nairobi, Kenya.
Corresponding author email: rukundoplacide@gmail.com, Tel: +250786112423 / +27783930397.

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ABSTRACT

Objective: To evaluate the yield performance of new potato clones under Rwanda climatic conditions in attempt for developing new potato varieties with market lead traits, that can replace the existing having more than 20 years old.
Methodology and Results: the Potato Sub-Program of Rwanda agriculture and Animal Resources Development board (RAB) in collaboration with the International Potato Center (CIP), has introduced and evaluated the yield performance of six advanced potato clones(CIP388676.1, CIP392657.8, CIP398190.89, CIP392797.22, CIP398193.511, and CIP394611.112), in comparison with most popular local varieties (Kinigi and Kirundo)under Rwanda climatic conditions. Trials were established at Kinini, Rwerere, and Tamira RAB Research Station located in a randomized complete block design with three replications for two growing seasons. The analysis of variance revealed high significant effects (p-value < 0.01) of genotype, site, season, genotype x site, and site x season on total tuber yields. A positive correlation of 90% was observed between number of tuber per plant and yield of no marketable roots. Across sites and seasons genotypes showed variation in the performance. The high average yields of 47.08 and 54.58 t/ha were observed at Rwerere, in season 2017B and season 2018A, respectively. The Kinigi site had tuber yields of 32.02 and 36.44 t/ha, while Tamira site has 20.25 and 35.71 t/ha for season 2017B and season 2018A, respectively. The Rwerere site revealed a high dry matter content compare to other sites. The dry matter was 22.18, 19.34 and 18.74% of tuber fresh weight for Rwerere, Kinigi and Tamira, respectively. At each site, the genotype CIP 394611.112 revealed the highest dry matter content, this dry matter content was 20.67, 25.95 and 20.78 % of tuber fresh weight at Kinigi, Rwerere and Tamira. This dry matter was higher than the dry matter content of local check Kinigi with 18.05, 21.42, and 19.11 %, and Kirundo with 16.69, 21.88 and 15.6% of tuber fresh weight at Kinigi, Rwerere, and Tamira respectively. The genotype CIP392657.8, CIP392797.22, CIP398190.89, Kinigi and Kirundo had marketable yields that are above 30 t/ha, while genotypes such as CIP388676.1, CIP394611.112 and CIP398193.511 revealed marketable yield which was below 27.5 t/ha.
Conclusion and Application of results: The clones CIP392657.8, CIP392797.22, and CIP398190.89 which showed the yields comparable to local checks are candidate for new potato varieties in Rwanda. The release of these new potato varieties will increase the number of approved varieties and farmers choices to diversify the potato production.
Keywords: Clone, performance, potato, yields

INTRODUCTION

Potato (*Solanum tuberosum*) is the fourth among the world's food crops after wheat, rice and maize. It is grown in more than 100 countries, under temperate, subtropical and tropical conditions, at an area estimated at 18.9 million hectares with annual yields estimated at 347 metric million tonnes, and productivity of 18.4 tons/ha (FAOSTAT, 2015; Addis *et al.,* 2017). Potato is a staple food for about one billion people in the world and about half of this population is localized in the developing counties. Among root and tuber crops, potato is the first in terms of volume produced and consumed followed by cassava, sweet potato and yams (FAOSTAT, 2015). More than one third of the global potato production comes from developing countries including Asia countries such as China, India, Indonesia, Nepal, and Pakistan, and Africa countries such as Egypt, Algeria Cameroon, South Africa, Morocco, Kenya, Uganda, Tanzania, and Rwanda (Okoboi, 2001; and Ferris *et al.,* 2002). In East Africa, Rwanda is leading in the potato production, while it is the third in Sub-Saharan Africa (USAID, 2016). Potato provides more nutritious food per unit of land in less time and under low water conditions than other food crops. It is one of the most efficient crops in converting natural resources into a high quality food, with high yielding and more responsive to agriculture inputs (Horton, 1987). Potatoes are a precious source of food for many low-income people in both urban and rural areas. They are consumed in different forms such as boiled, roasted, French fried and chipped (Kibar, 2012). Potatoes are very rich in various nutrients such as carbohydrates, minerals (calcium, phosphorus), vitamins (ascorbic acid, niacin, thiamine and riboflavin), fibres, and proteins (Woolfe and Poates, 1987, Tamm, 2007, Horton, 1987). It was proved that the protein of potato is very rich in lysine and low in sulphur holding amino acids (Bouis and Scott, 1996). These nutrients of potato make it a healthy staple food. Tubers of potatoes are also raw materials for chips (fries), crisps, starch, spirits and alcohol industries (Mujaya and Mereki, 2010). All this value of potato makes it highly adopted by farmers and promoted by governmental agriculture agencies. In Rwanda potato is an important crop grown for family food security and income generation with a high potential for export. It was introduced in Rwanda at the beginning of the 19th century and is now being cultivated throughout the country, particularly in the Northern Province (Birunga and Buberuka high lands agro ecological zones), Western Province (Birunga and Congo Nil Watershed Divine agro-ecological zones), and Southern Province (Congo Nil Watershed Divine agro-ecological zone), where rainfall and soil conditions are favourable. Since its introduction, its acreage, production and annual per capita consumption have increased with time, from 19,300 to 164,152 ha, 96,500 to 1.3 million tons and 8 to 145 kg, from 1961 to 2014, respectively (FAOSTAT, 2015). Potato covers 4% of total cultivated land per each growing season, but it provides 10% of total main crop production in Rwanda (INSR, 2015). Most of potato sector consists of small family farms that intercrop potato with beans and maize, and yields average is still low (around 10 tons/ha) compared to other countries that can reach up to 40 tons/ha (ISAR, 2008). The challenges of this low potato productivity include small and fragmented potato production land, poor linkage of potato producers and markets, limited access to credit for agriculture inputs, shortage of appropriate post-harvest handling and processing technologies, inadequate supply of high quality seeds to farmers, low rate of fertilizer use and irrigation, pest and disease problems, and limited number of high yielding adapted potato varieties meeting the end users' preferences (Muthoni and Nyamongo, 2009; Muhinyuza *et al.,* . 2012). The National Program for Potato Improvement (PNAP) was established by Rwanda Institute for Agricultural Sciences (ISAR) in cooperation with the International Potato Center (CIP) in 1979. This program had a mandate of selection and multiplication of improved potato varieties for Rwandan conditions, production and distribution of improved seeds, development and transfer of technologies to increase potato production (Monares, 1984, Haverkort and Bicamumpaka, 1986). Most of the current famous grown potato varieties in Rwanda were developed by this program before 1994 genocide that destroyed the country's infrastructure including PNAP facilities (Fané *et al.,* . 2006). These varieties were developed based on the needs of that time. Nowadays, the needs have changed. For example, the established potato processing industries require potato with specific characteristics such as high dry matter content, low reducing sugar content, good shape, and shallow eyes (USAID, 2016). In addition to change in needs, the current climate changes brought new biotic and abiotic stresses (Tesfahun, 2018). In an attempt to developing new potato varieties resistant or tolerant to current potato production constraints with market led traits, that can replace the existing having more than 20 years old, the Potato Sub-Program of Rwanda agriculture and Animal Resources

Development Board (RAB) in collaboration with the International Potato Center (CIP), has introduced advanced potato clones from Lima, Peru. The objective of this study was to evaluate their yield performance under Rwanda climatic conditions.

MATERIALS AND METHODS

Planting materials: The planting materials tested in this study are six CIP potato clones (CIP388676.1, CIP392657.8, CIP398190.89, CIP392797.22, CIP398193.511, and CIP394611.112) and two local checks (Kinigi and Kirundo). The descriptions of these materials are detailed in Table 1 and Figure 1 and 2.

Table 1: Description of tested potato varieties and clones.

No	Clone/varieties	Origin	Pedigree	Dormancy period	Late Blight
1	CIP388676.1	Peru	378015.18 x PVY-BK	73	No data
2	CIP392657.8	Peru	387341.1 x 387170.9	-	Resistant
3	CIP398190.89	Peru	393077.54 x 392639.2	-	Resistant
4	CIP392797.22	Peru	387521.3 x APHRODITE	109	Susceptible
5	CIP398193.511	Peru	393077.54 x 392633.64	-	Resistant
6	CIP394611.112	Peru	PW-88.6203 x 676008=(I-1039)	109	Highly Resistant
7	Kinigi	Local check	65-ZA-5 x YY.1	90	-
8	Kirundo	Local check		60	-

Figure 1: Vegetative appearance of tested potato materials (CIP388676.1, CIP398190.89, CIP392797.22, CIP394611.112, CIP398193.511 and Kirundo.

Figure 2: Tubers appearance of tested potato materials (CIP388676.1, CIP398190.89, CIP392797.22, CIP394611.112, CIP398193.511 and Kirundo).

Description of study sites: The study was carried out in two growing seasons (season 2017B: February-July), and season 2018A: August-December) at Kinini and Rwerere RAB Research Stations located in Musanze and Burera Districts, respectively, of Northern Province, and Tamira RAB Research Station located in Rubavu District of Western Province of Rwanda. The Kinigi RAB Research Station is located at an altitude of 2200m above sea level, on longitude of 29°38’ East and latitude of 1°30’ South. This area has 20% organic volcanic soils. It receives bimodal rainfall with the short and long rains being received in October to December and March to June, respectively. The annual mean temperature and rainfall received is 18°C and 1400mm, respectively. Rwerere RAB Research Station is located at an altitude ranging between 2,060 and 2,312m above sea level, on longitude of 29° 19’ East and latitude of 1°36’ South with an annual rainfall and temperature of 1200mm and 20ºC, respectively. Tamira RAB Research Station is located at latitude of 1º 55' South and longitude of 29º 38' East, with an altitude of 2,340m above sea level. This research station has an annual rainfall and temperature estimated at more than 1450mm, and 15°C, respectively (RAB, 2014). Kinigi and Tamira have soils derived from volcanic parental materials and are considered to be the best agricultural land in Rwanda, while the soil of Rwerere Research Station is acidic with texture of loamy sand. The chemical properties of trial sites are detailed in table 2.

Table 2: Chemical properties of soils at Kinigi, Rwerere and Tamira sites.

Soil properties	Kinigi	Rwerere	Tamira
pH - H2O	6.3	4.8	6.2
KCl	5.6	3.7	5.4
Organic carbon (%)	2.01	1.5	2.08
N (%)	0.25	0.11	0.66
P (mg/kg)	11.1	3.63	2.68
K (cmol/kg)	2.01	0.12	2.08
Ca (cmol/kg)	14.4	1.3	26
Mg (cmol/kg)	5.8	0.5	6.6

Trial establishment: The trials were laid out in a randomized complete block design with three replications. The spacing between plants, rows, and replicates was 30cm, 80cm, and 150cm, respectively. The experimental plot had 40 plants grown on four rows. The planting depth was 6-8 cm, and sowing rate was one tuber per hill. The trial was surrounded by two border rows planted with kinigi. The manure fertilizer was applied during planting at a rate of 20t/ha and mineral fertilizer ($N_{17}P_{17}K_{17}$) was applied at a rate of 300kg/ha. A half (150kg/ha) of mineral fertilizer ($N_{17}P_{17}K_{17}$) was applied during planting, and another half during earthing up while the total amount of organic manure was applied during planting. The weeding was carried out manually when was needed. The insect pests were controlled by spraying using alternate products which have the active ingredients of Abamectin 18g/l, and Profenofos 40% + Cypermethrin 4% EC. Late blight disease was controlled by spraying Ridomil, a systemic fungicide applied at 30 days after planting at about 95% crop emergence at a concentration of 50g/15liters of water. This application of systemic fungicide was repeated two times with an interval of seven days. After application of Ridomil, late blight disease was continuously controlled by spraying Dithane (Mancozeb), a contact fungicide at a dose of 50g/15liters of water. Spraying was repeated every seven days to ensure full control of late blight disease. The trial was dehaulmed at fully maturity (120 days after planting). Harvesting was carried out at 135 days after planting.

Data collection: The yield data including number and weight of tuber per plot, total yields, marketable and no marketable yields, and dry matter content of tubers were collected at harvesting following the approach described by De Haan *et al.,* . (2014).To determine the marketable and no marketable yields, the tubers were sorted and classified into three groups: Tubers weighing 200-300g or tubers with a diameter of 60mm, 80-200g or tubers having diameter ranging between 30-60mm, and tubers weighing less of 80g or with a diameter that is less than 30mm. The number and weight of tubers of each category and for each clone were determined. The category one and two were classified in marketable yields while the last category was classified as no marketable yields. The dry matter content was determined after modifying the methods described by Carey and Reynoso (1996) and Tairo *et al.,.* (2008).Ten to twelve healthy potato tubers were randomly selected. From fresh collected root samples, three roots of each genotype were again sampled. Approximately 50 to 55 g of fresh weight were excised and kept in a paper bag prior to drying. Samples were dried in an oven at 70^oC for 72 hours. Dried samples were weighed with sensitive balance and the dry matter content was determined using the following formula: Dry matter content (DM) % = ((Dry weight/Fresh weight) x 100).

Data analysis: The data collected was processed by analysis of variance (ANOVA) using GenStat 15^{th} edition (Payne *et al.,.* 2011). When the significant differences among genotypes, sites, and seasons were detected, its separation was performed with the least significant difference (LSD) test (P = 0.01 and P= 0.05) (Cochran and Cox, 1992). The ranking of best performing potato clones in each environment were performed with the additive main effects and multiplicative interaction (AMMI) (Gauch and Zobel, 1996).

RESULTS

Analysis of variance: The analysis of variance revealed high significant effects (p-value < 0.01) of genotype and site, and significant effects (p-value < 0.05) of season on the number of tubers per plant. The effects of genotype x site, genotype x season, and genotype x site x season were not significantly different

(Table 3). The effects of genotype, site, season, genotype x site, site x season on average yield per plant were highly significant (p-value < 0.01). The effects of genotype x site x season were significant while the effects of genotype x season were not significant (p-value < 0.05) (Table 3). It was observed that the effects of genotype, site, season, genotype x site, site x season, genotype x season, and genotype x site x season on marketable and non-marketable yields were highly significant (p-value < 0.01) (Table 3). The high significant effects (p-value < 0.01) of genotype, site, season, genotype x site, and site x season were observed on total tuber yield. It was also observed the significant effects (p-value < 0.05) of genotype x site x season and no significant effects of genotype x season on the total tuber yields (Table 3).

Table 3: Analysis of variance for number of tubers per plant, average yield per plant, marketable, non- marketable and total yields, and dry matter content of tubers of CIP potato advanced clones.

Source of variation	**Df**	**Number of tuber/plant**	**Average yield/plant**	**Marketable yields (t/ha)**	**Non marketable yields (t/ha)**	**Total yields (/ha)**	**DMC**	
							Df	**SS**
Replication	2	19.33	0.01	1.8	10	20.2	1	3.3
Variety/ clone	7	307.73**	3.69**	4138.1**	549.51**	6403.6**	8	90.8**
Site	2	822.93**	10.70**	34607.4**	4903.10**	18576.5**		
Season	1	8.36*	0.91**	12372.9**	5109.91**	1580.1**	2	121.3 **
Genotype x Site	14	147.61**	2.19**	4724.2**	394.31**	3809.8**		
Genotype x Season	7	10.89^{ns}	1.81^{ns}	1239.3**	446.30**	635.8^{ns}	16	68.9*
Site x Season	2	4.66^{ns}	0.88**	6693.7**	5012.64**	1521.9**		
Genotype x Site x Season	14	26.18^{ns}	2.22*	1830.5**	425.97**	1557.6*		
Residual	94	189.52	2.72	4409.2	327	4717.1	26	48.0
Total	143	1537.20	22.36	70017.0	17179	38822.6	53	332.3

(Number in table are sum of squares, **: significant difference at 0.01, *: significant difference at 0.05, ^{ns}: not significant, DM: Dry matter content, Df: degree of freedom).

The genotypes revealed variations in the number of tubers per plant (Table 4). The highest roots number of 11.5, 10.6 and 9.7 were observed on Kirundo, CIP398190.89 and Kinigi. These genotypes did not show a significant difference. The lowest roots number of 6.5 and 7.7 was observed on the genotypes CIP398193.511 and CIP388676.1. These clones revealed significant differences with other genotypes. Average yields per plant estimated at almost 1kg was observed on genotypes CIP392657.8, Kirundo, CIP392797.22, Kinigi and CIP398190.89 (Table 4). The genotype that revealed the lowest average yields per plant of 0.798 kg was CIP388676.1 (Table 4). The tested genotypes revealed two main groups of marketable root yields (Table 4). The genotype CIP392657.8, CIP392797.22, CIP398190.89, Kinigi and Kirundo had marketable yields that are above 30 t/ha, while genotypes such as CIP388676.1, CIP394611.112 and CIP398193.511 revealed marketable yield which was below 27.5 t/ha (Table 4). A positive correlation of 90% was observed between number of tuber per plant and yield of no marketable roots. The genotypes such as Kirundo, CIP398190.89, and Kinigi with high roots number per plant, revealed the highest yields of no marketable roots. Their no marketable yields were estimated at 11.4 t/ha, 8.5, 7.4 t/ha (Table 4). In terms of total tuber yields, genotypes CIP392657.8, Kirundo, CIP392797.22, Kinigi and CIP398190.89 revealed a high yield estimated between 40.3 and 46.3 t/ha. The clone that revealed the lowest yields were CIP398193.511 and CIP388676.1. Their yields were 27.7 and 31.2 t/ha, respectively (Table 4). The genotype CIP394611.112 revealed a high dry matter content of 22.5 % compared to other tested genotype. The other genotype such as CIP398190.89 (20.5%), CIP398193.511 (20.5%), CIP392657.8 (19.8%), Kinigi (19.5%), CIP388676.1 (19.4%), CIP392797.22 and Kirundo (18.1%) did not show significant difference (Table 4).

Table 4: Average number of tubers per plant, average yield per plant, marketable, non- marketable and total yields, and dry matter content of tubers of CIP potato advanced clones.

Genotype	Number tuber per plant	Average yield/plant (kg)	Marketable yield (t/ha)	No-marketable yield (t/ha)	Total yield (t/ha)	DMC (%)
CIP388676.1	7.7[b]	0.798[ab]	25.8[a]	5.5[ab]	31.2[ab]	19.4[abc]
CIP392657.8	8.8[c]	1.110[d]	39.5[c]	6.76[c]	46.3[d]	19.8[bc]
CIP392797.22	8.9[c]	1.050[cd]	35.3[bc]	8.4[d]	43.8[cd]	18.8[ab]
CIP394611.112	9.6[c]	0.803[b]	27.2[a]	6.2[bc]	33.5[b]	22.5[e]
CIP398190.89	10.6[de]	0.968[c]	31.8[b]	8.5[d]	40.3[c]	20.6[cd]
CIP398193.511	6.5[a]	0.664[a]	22.8[a]	4.8[a]	27.7[a]	20.5[cd]
Kinigi	9.7[cd]	1.040[cd]	35.9[bc]	7.4[cd]	43.3[cd]	19.5[abc]
Kirundo	11.5[e]	1.089[d]	33.9[b]	11.4[e]	45.4[d]	18.1[a]

(Means vertically followed by the same letter are not significantly different).

Across sites and seasons genotypes showed variation in the performance. The high average yields of 47.08 and 54.58 t/ha were observed at Rwerere, in season 2017B and season 2018A, respectively (Table 5). The Kinigi site had a yield of 32.02 and 36.44 t/ha, while Tamira site had 20.25 and 35.71 t/ha for season 2017B and season 2018A, respectively (Table 5). The season 2018A showed a high yield compared to season 2017B (Table 5). At Kinigi the best genotype was CIP392797.22. This genotype revealed a yield of 40.31 t/ha while the local check, Kinigi and Kirundo had 33.33 and 35.31 t/ha, respectively (Table 5). At Rwerere, the best genotype was CIP392657.8 with 68.25 t/ha. The local check of Kinigi and Kirundo showed an average yield of 60.86 and 58.18 t/ha, respectively (Table 5). A local check Kirundo had a highest yield of 37.67 t/ha at Ramita. The good performing CIP advanced clones at this site were CIP392797.22 with 32.48 t/ha, CIP398190.89 with 31.83 t/ha, and CIP392657.8 with 28.08 t/ha (Table 5).

Table 5: AMMI-estimates of yields per site and season of potato varieties and advanced CIP clones.

Genotype	Kinigi			Rwerere			Tamira		
	Season 2017B	Season 2018A	Average	Season 2017B	Season 2018A	Average	Season 2017B	Season 2018A	Average
CIP388676.1	30.8	35.15	32.975	33.84	38.84	36.34	21.9	21.9	21.9
CIP392657.8	27.24	44.61	35.925	61.75	74.75	68.25	18.78	37.38	28.08
CIP392797.22	33.98	46.63	40.305	49.46	58.46	53.96	22.03	42.93	32.48
CIP394611.112	31.22	27.71	29.465	44.21	49.21	46.71	12.63	30.86	21.745
CIP398190.89	37.88	36.51	37.195	47.98	51.98	49.98	16.45	47.22	31.835
CIP398193.511	25.45	33.27	29.36	30.37	34.37	32.37	19.27	19.27	19.27
Kinigi	27.78	38.87	33.325	55.86	65.86	60.86	21.95	39.71	30.83
Kirundo	41.84	28.78	35.31	53.18	63.18	58.18	28.97	46.37	37.67
Average	32.02	36.44	34.23	47.08	54.58	50.83	20.25	35.71	27.98

The Rwerere site revealed a high dry matter content compare to other sites. The dry matter content was 22.18, 19.34 and 18.74% of tuber fresh weight, at Rwerere, Kinigi, and Tamira, respectively (Table 6). At each site, the genotype CIP 394611.112 revealed the highest dry matter content, this dry matter content was 20.67, 25.95 and 20.78 % of tuber fresh weight at Kinigi, Rwerere and Tamira. This dry matter was higher than the dry matter content of local check Kinigi with 18.05, 21.42, and 19.11 %, and Kirundo with 16.69, 21.88 and 15.6% of tuber fresh weight at Kinigi, Rwerere, and Tamira, respectively (Table 6).

Table 6: AMMI-estimates of DMC (%) per site of potato varieties and advanced CIP clones.

Variety/Clone	Kinigi	Rwerere	Tamira
CIP 388676.1	19.36	19.44	19.46
CIP 392657.8	19.17	22.74	17.49
CIP 392797.22	18.45	20.91	16.97
CIP 394611.112	20.67	25.95	20.78
CIP 398190.89	20.01	24.37	17.31
CIP 398193.511	20.12	21.23	20.24
Kinigi	18.05	21.42	19.11
Kirundo	16.69	21.88	15.6
Average	19.34	22.18	18.74

DISCUSSION

In the study of genotype by environment interaction for tuber yield, dry matter content and specific gravity in elite tetraploid potato (*SolanumTuberosum* L.) genotypes, Tsegaw (2011) reported significant variations among genotypes with respect to tuber yields and dry matter content. He also observed significant effects of genotype by environment interaction for yield and dry matter content of potato tubers. Significant variations were revealed among potato varieties for no marketable and marketable tuber yields, and number and weight of tubers per plant (Addis *et al.,*. 2017). Tapiwa (2016) reported a significant difference in the yields due to genetic makeup of potato varieties. Combined analysis of variance revealed that the main effects due to environment (E), genotype (E) and genotype by environment (GxE) interaction were highly significant. The contribution of E, G and GxE interaction to the total variation in tuber yields was estimated at 47.11%, 8.83% and 44.07%, respectively (Mulugeta and Dessalegn, 2014). The results from this study support the previous findings (Table 3). The analysis of variance revealed that the effects of genotype, site and season, and genotype x site interaction on number of tubers and average yield per plant, marketable, no-marketable, and total yields, and dry matter content of potato tubers were significant. The effects of genotype x season interaction were significant on marketable and no marketable yields, but these effects were not significant on the average tuber yield per plant and total yields. The interaction effects of site x season, and genotype x site x season on average yield per plant, marketable, no-marketable, and total yield of tubers were significant. The interaction effects of genotype x season, site x season, and genotype x site x season on number of tubers per plant were not significant. The observations of this study suggested that genotype, site, season and interaction between genotype and site have a strong influence on the potato tuber yields and dry matter content, while the influence of genotype x season, site x season, and genotype x site x season interactions on the number of tubers per plant is very low. The highest number of tuber per plant of 13 was reported by Ahmed *et al.,* (2007) in his study aiming at analysing the growth, development indices of different potato varieties and yield of potato in relation to planting date. The results from this study showed variations in the number of tubers per plant (Table 4). The highest tubers number of 11.5, 10.6 and 9.7 were observed on Kirundo, CIP398190.89 and Kinigi, respectively. These genotypes did not show a significant difference. The lowest tubers number of 6.5 and 7.7 was observed on the genotypes CIP398193.511 and CIP388676.1. These clones revealed significant differences with other genotypes. The number of tubers per plant from this study is low compared to results from other studies. It was reported that genotype, environment and their interaction affect strongly the number of tubers per plant (Ahmed *et al.,* 2007). The same observations were noticed in this study. The tested clones were grown in the same conditions. Therefore, the observed differences of number of tubers per plant are associated with genotype capacity to use available resources in the environment. The marketable yield is some very important criteria to select potato clones for high yield (De Haan *et al.,* 2014). The tested genotypes revealed two main groups of marketable root yields (Table 4). The genotype CIP392657.8, CIP392797.22, CIP398190.89, Kinigi and Kirundo had marketable yields that are above 30 t/ha, while genotypes such as CIP388676.1, CIP394611.112 and CIP398193.511 revealed marketable yield which was below 27.5 t/ha (Table 4). The yield of clones CIP392657.8, CIP392797.22, and CIP398190.89 which are in the same range with local checks revealed that they are candidate for new potato varieties in Rwanda. Addis *et al.,* . (2017) observed that genotypes with high number of tubers present low total yields and marketable yields, because most of these tubers are no marketable tubers. This observation agrees with the findings of this study where a positive correlation of 90% was observed between number of tubers per plant and yield of no marketable roots. However, a disagreement was noticed. Through this study, the genotypes such as Kirundo, CIP398190.89, CIP392797.22, and Kinigi with high roots number per plant, and highest yields of no marketable roots, revealed also the highest total tuber yields (Table 4). The results of this study; a positive correlation between number of tubers per plant and yield of no marketable roots, and the absence of the relationship between number of tubers per plant and total yields, suggest that the number of tubers per plant can be used in the indirect selection for high marketable yields. In evaluation of new potato varieties for yield potential in Zimbabwe, Tapiwa (2016) achieved the highest yields of 69.63 and 58.89 t/ha, while the lowest yields were ranging between 13.22 and 9.89 t/ha. The highest yield of (34 t/ha) was recorded on variety Pamela, the lowest yield of (19 t/ha was recorded on the variety Labella, while the variety Desiree considered as local check provided a yield of 24 t/ha in the study to identify the responsiveness of different potato varieties to phosphorus fertilizer (Khalid *et al.,* 2014). The total tuber yields of tested genotypes were estimated between 40.3 and 46.3 t/ha for CIP392657.8, Kirundo, CIP392797.22, Kinigi and CIP398190.89. The clones that revealed the lowest yields were CIP398193.511 and CIP388676.1. Their yields were 27.7 and 31.2 t/ha, respectively (Table 4). Based on results from above cited studies, it is noticeable that the new tested potato clones had a higher yield potential. Climate, cultivar, and crop management determine the growth and dry matter production of potatoes. Drought and high temperature affect leaf area development and its persistence, and these limit the photosynthetic activity of the crop, and finally dry matter production and allocation (Geremew *et al.,* 2007). The earlier maturing potato varieties revealed a high tuber dry matter accumulation, but this observation did not necessarily indicate a high final yield. It was reported that the earlier potato genotypes perform all the growth activities and dry matter accumulation in a short period of time, compared with later maturing genotypes. Nonetheless, this growth character does not favour for high tuber yield, because, dry matter partitioning to tuber is genotype-specific, and requires prolonged vegetative growth (Geremew *et al.,* 2007). Among tested genotypes, none was found to be stable and ranked at the top for tuber yield, dry matter content and specific gravity. The stability and responsiveness appeared to be specific for specific character within a single genotype (Tsegaw, 2011). Across different environments, the potato genotypes revealed differential responses to tuber yields and dry matter content (Tsegaw, 2011). The genotype CIP394611.112 revealed a high dry matter content of 22.5 % compared to other tested genotype. The other genotypes such as CIP398190.89 (20.5%), CIP398193.511 (20.5%), CIP392657.8 (19.8%), Kinigi (19.5%), CIP388676.1 (19.4%), CIP392797.22 and Kirundo (18.1%) did not show significant difference (Table 4). All potato clones were grown in the same conditions. Therefore, the observed variations in dry matter content among tested potato clones are the result of genotype effects. The farmers need varieties that show high performance for yield and other essential agronomic traits. Their superiority should be reliable over a wide range of environmental conditions and also over years. The basic cause for difference in the performance of genotypes over environments is the occurrence of genotype by environment interaction. To overcome problem of genotype by environment interaction, trials are usually conducted over several locations and years to ensure that the selected genotypes have a high and stable performance over a wide range of environments (Mulugeta and Yigzaw, 2014). Through the same approach, the results of this study showed that the season 2018A provided a high yield compared to season 2017B (Table 5). Across sites and seasons, genotypes showed variation in the performance. The high average yields of 47.08 and 54.58 t/ha was observed at Rwerere, in season 2017B and season 2018A, respectively (Table 5). The Kinigi site had a tuber yield of 32.02 and 36.44 t/ha, while Tamira site had 20.25 and 35.71 t/ha for season 2017B and season 2018A, respectively (Table 5). These findings suggest that specific clones with specific adaptation should be selected for each site. Under appropriate agro-technology, meteorological conditions contribute about 40% of variation in potato yields. According to Katarzyna, 2015), the rainfall affects early potato yields more than temperature. Under the natural climatic conditions, potato growth and yields depend on soil nutrients, cultivation practices, and weather, in particular temperature and precipitation. However, combined effects of temperature and precipitation are very critical for growth and yield of potato (Borkowska and Grundas, 2007; Rymuza *et al.,* 2015). High temperature decreases yield due to physiological and biochemical changes occurring in the plant, such as photosynthesis, respiration and water status. A negative impact of too high temperature can be reduced by evenly distributed optimum precipitation. However, in practice rainfall distribution cannot be controlled (Kalbarczyk, 2003). Therefore, the discrepancies of yields observed between seasons, and among trial sites could be associated with variation of weather conditions, and soil nutrients. Trials carried out across various locations allow for the separation of effects due to genotypes, genotype by environment interaction and plot error. With these trials, it is possible to identify the stability of each genotype and its parameters, which are considered as supplementary characters associated with yield. Therefore, multi-locational trials are very important to determine the yield potential of the varieties in the different farming regions of the country (Tapiwa, 2016). Adaptability of crop variety may vary from one location to another, depending on the agro-ecology of a particular area. Thus, it is essential to conduct location specific adaptation trials to identify suitable varieties (Addis *et al.,* 2017). At each site, tested genotypes showed variation in the yield performance (Table 5). At Kinigi, the best genotype was CIP392797.22. This genotype revealed a yield of 40.31 t/ha while the local check, Kinigi and Kirundo had 33.33 and 35.31 t/ha, respectively. At Rwerere, the best genotype was CIP392657.8 with 68.25 t/ha. The local check of Kinigi and Kirundo showed an average yield of 60.86 and 58.18 t/ha, respectively. A local check Kirundo had a highest yield of 37.67 t/ha at Tamita. The good performing CIP advance clones at this site were CIP392797.22 with 32.48 t/ha, CIP398190.89 with 31.83 t/ha, and CIP392657.8 with 28.08 t/ha. These results revealed that the CIP advanced clones of CIP392797.22 and CIP392657.8 have a broad adaptability across three sites where the trials were carried out. The Rwerere site revealed a high dry matter content compare to other sites. The dry matter content was 22.18, 19.34 and 18.74% of tuber fresh weight for Rwerer, Kinigi and Tamira, respectively (Table 6). At each site, the genotype CIP 394611.112 revealed the highest dry matter content. This dry matter content was 20.67, 25.95 and 20.78 % of tuber fresh weight at Kinigi, Rwerere and Tamira, respectively (Table 6). This dry matter was higher than the dry matter content of local checks Kinigi with 18.05, 21.42, and 19.11 %, and Kirundo with 16.69, 21.88 and 15.6% of tuber fresh weight at Kinigi, Rwerere, and Tamira, respectively (Table 6). Sofield (1977) reported that the time of planting has great influence on dry matter accumulation. This observation is different from results of this study because all trials were established at the same time. It seems that the variations observed are due to variations in trial sites. This was also reported by Ahmed *et al.,* (2007). The soil nutrients, elevation, temperature, rain fall of Rwere, Kinigi and Tamira sites are different. These suggest differential responses of tested genotypes to soils nutrients at the three locations, due to differences in elevation, temperature, and soil properties.

RECOMMENDATIONS

The results of this study suggested that genotype, site, season and interaction between genotype and site have a strong influence on the potato tuber yields and dry matter content, while the influence of genotype x season, site x season, and genotype x site x season interactions on the number of tubers per plant is very low. A strong and positive correlation between number of tubers per plant and yield of no marketable roots, and the absence of the relationship between number of tubers per plant and total yields, suggest that the number of tubers per plant can be used in the indirect selection for high marketable yields. All potato clones were grown in the same conditions but expressed the variation in dry matter content. This variation of dry matter content is a result of genotype effects. The discrepancies of yields observed between seasons, and among trial sites could be associated with variation of weather conditions, and soil nutrients. The soil nutrients, elevation, temperature, and rain fall of Rwerere, Kinigi and Tamira sites are different. These suggest various responses of tested genotypes to these environments. The yield performance of the tested clones of CIP392797.22 and CIP392657.8 showed that they have a broad adaptability across three sites where the trials were carried out. The marketable and total yields of clones CIP392657.8, CIP392797.22, and CIP398190.89 which are in the same range with local checks suggest that they are candidate for new potato varieties in Rwanda.

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