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Performance of CIP and Dutch potato varieties under Rwanda climate conditions

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In attempt to develop new potato varieties with the current market lead traits, nine Dutch potato varieties namely Fabula, Panamela, Sagitta, Challenger, Sifra, Rosi, Memphis, Taurus and Derby, and International Potato Center (CIP) varieties Kinigi and Kirundo were evaluated in three Rwandan sites for two growing seasons in a randomized complete block design (RCBD) with tree replications. The data collected consists of plant vigor, late blight incidence and severity, yields and processing qualities. The collected data were submitted to analysis of variance. The results showed that variety, site, season, and all interactions of main variation factors have significant effects on total yields. The average total yields of CIP varieties were extremely high and significantly different compared to tested Dutch varieties. These yields were 34.2 and 30.7 tons ha^{-1} for Kirundo and Kinigi, respectively. The best performing among tested Dutch varieties were Panamela with 20.2 tons ha^{-1}, Rosi with 16.4 ton ha^{-1}, Sagita with 15.8 tons ha^{-1}, and Taurus with 14.4 tons ha^{-1}. The CIP varieties Kinigi (7.2 score) and Kirundo (7.2 score) revealed a big plant vigour compared to tested Dutch varieties. Among Dutch varieties, Taurus (6.9 score) and Panamela (6.2 score) showed the highest plant vogour. CIP varieties Kinigi and Kirundo, and Dutch varieties Sifra and Taurus revealed the same trends for late blight (less than 30% of plants revealed late blight symptoms. Taurus, Challenger, and panamela revealed the highest dry matter content of 22.4, 21.7, and 20.0%, respectively. This dry matter content is high compared to CIP varieties Kinigi (19.20%), commonly used for French fries and crisps in Rwanda. Dutch varieties Rosi, Challenger and Taurus revealed crisps with yellow color without rolling. Panamela and Kinigi showed crisps with similar characteristics. The results from this study suggested that any private company planning to invest in potato processing for French fries and crisps, the Dutch varieties such as Rosi, Challenger, Taurus and Panamela are good candidates for raw materials.

Key words: Crisps, Dutch, yield, blight symptoms.

INTRODUCTION

Potatoes (*Solanum tuberosum*) is the fourth among the world's food crops after wheat, rice and maize, grown in more than 100 countries at an area estimated at 18.4 million hectares of land, with a productivity of 18.4 ton ha^{-1} and annual production of 347 million tons (FAOSTAT, 2015). Globally, it is the third consumed food commodity

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after rice and wheat and has therefore been recommended as a food security crop by the Food and Agriculture Organization of the United Nations. Potato is viewed as an important food crop to face the world uncertainties in food supply, and steady hunger rates of the current growing population leading to an increasing demand for food (FAO, 2009; Devaux et al., 2014). Potato provides more food with high nutrient content in a short period (FAO, 2008; Lutaladio and Castaldi, 2009). Currently, the cultivation of potato is becoming an integral part of the global food system based on nutritional value, and social and economic importance of this plant (Paul, 1985).

Rwanda is one of the sixth potato producing countries in Africa after Egypt, Malawi, Kenya, Algeria, South Africa, and the third in sub-Saharan Africa, and the largest producer of potatoes in East Africa (CIP, 2011; FAOSTAT, 2015). Potato is one of the six priority crops (potato, maize, rice, wheat, cassava and beans) supported in the Crop Intensification Program established by the Ministry of Agriculture and Animal Recourses in Rwanda (Kathiresan, 2011). Due to the growing market demand in Rwanda and neighbouring countries (USAID, 2016), potato production has increased substantially, particularly in the Northern and Western provinces of Rwanda where agricultural conditions are favourable for potato production (MINAGRI, 2014).

It covers 4% of total cultivated land in each growing season, and provides 10% of total production of main food crops in Rwanda (NISR, 2015). Most potato cultivation consists of small family farms that intercrop potato with beans and maize, and the yield average is still low (around 10 tons ha^{-1}) compared to other countries that can reach up to 35 tons ha^{-1} (FAOSTAT, 2015). This low productivity is mainly due to low soil fertility, unavailability of clean seeds, poor market accessibility and lack of financial investment, a range of diseases, and lack of access to high yielding varieties (Muhinyuza et al., 2012). Most of the current famous grown potato varieties in Rwanda have been developed 20 years ago, based on needs of that time (Monares, 1984; Muhinyuza et al., 2012). Nowadays, end users' needs have changed. Current established potato processing plants require potato with specific characteristics such as high dry matter, low reducing sugar content, good shape and shallow eyes. In attempt to develop other potato varieties meeting end user's preferences, the RAB Potato Sub-Programme has introduced and evaluated nine new potato varieties, in The Netherlands in comparison with CIP varieties. This publication reports the results.

MATERIALS AND METHODS

Planting

Nine Dutch potato varieties (Fabula, Panamera, Sagitta, Challenger, Sifra, Rosi, Memphis, Taurus and Derby) belonging to The Netherlands were introduced in the form of minitubers by BRAMIN Ltd., in March 2015. After seeds increase, trials were established with Dutch varieties and two CIP varieties Kinigi (CIP 378699.2) and Kirundo (CIP 8212.5). The description of tested materials is shown in Table 1.

Trial establishment

The National Performance Trials (NPTs) were established at Cyanika sector in Burera district (2,300 m), Cyuve sector in Musanze district (1,860 m), and Mudende sector in Rubavu district (2,300 m) for two growing seasons. Cyanika site has an annual rainfall and temperature of 1200 mm and 20°C, respectively, while Mudende receives an annual average rainfall and temperature estimated at more than 1450 mm, and 15°C, respectively. The soils of both sites were derived from volcanic parental materials. Cyuve has 20% organic volcanic soils and 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 18.5°C and 1400 mm, respectively (RAB, 2014). The first season was carried out from March to July 2017 and the second season was performed from September 2017 to February 2018. Trials were established in a randomized complete block design with three replications of 40 hills per plot. The experimental plot consisted of four rows with ten plants in each row. The spacing was 80 and 30 cm between rows and plants, respectively. Trials were surrounded with three guard rows planted with Kinigi potato variety. Fertilizers $N_{17}P_{17}K_{17}$ and Urea (46-0-0) were applied at planting with a rate of 300 and 200 kg/ha, respectively. Aphids (virus vectors) and other insects were controlled by applying Rocket 44 EC (Profenofos 40% + cypermethrin 4% EC) at a dilution of 30 ml in 15 L of water. Late blight was controlled by using Dithane M45, a contact fungicide, wettable powder 80% Mancozeb at a rate of 2.5 g/L sprayed before the appearance of symptoms of late blight infection and by Ridomil gold, a systemic fungicide, wettable powder 64% Mancozeb, 4% Metalaxil at a rate of 2.5 g/L when symptoms appear. The trials were treated with Ridomil gold once and Dithane M45 eight times with 7 days of intervals. The weeding was carried out manually during the growth of the crop, when it was needed. Soil ridging up was also done manually and no irrigation was applied. Trials were managed by farmers who carried out all crop husbandry activities, and dehaulmed at fully maturity (120 days after planting). Harvesting was carried out at 135 days after planting.

Data collection

Disease and pest data

Late blight damage was assessed visually using the scale of 1-9, where no symptom, 5: medium (20-50%) damage and 9: very severe (75-100%) damage at 60 days after planting. Virus disease and leaf infection were assessed using a score of 0 to 5, where 0: (0-5%), no serous symptom, 1: (6-15%) maximum foliage infected is below 20%, 2: (16-35%) about 25% of foliage is affected, 3: (36-65%) about 50% of foliage area is affected, 4: (66-85%) about 75% forage area is affected, 5: (86-100%) all leave are affected or dead (Bonierbale et al., 2006).

Yield data

The yield data including total yield, marketable and unmarketable yields, number and weight of tubers per plot, and dry matter content of tubers were collected at harvesting following the approach

Table 1. Characteristics of tested materials.

Variety	Maturity	Skin colour	Flesh colour	Shape
Challenger	Medium late	Yellow	Light yellow	Oval / Long oval
Derby	Early	Yellow	Light yellow	Oval
Fabula	Medium late	Yellow	Light yellow	Oval
Memphis	Medium early	Red	Light yellow	Oval / Long oval
Panamera	Late	Yellow	Light yellow	Oval
Rosi	Late	Red	Light yellow	Oval
Sagitta	Medium early	Yellow	Light yellow	Oval
Sifra	Late	Light yellow	Cream	Round oval
Taurus	Medium late	Yellow	Light yellow	Round / Round oval
Kinigi	Medium late	Red	Light yellow	Round
Kirundo	Medium early	white	Light yellow	Round oval

described by De Haan et al. (2014). To determine the marketable and unmarketable yields, tubers were sorted and classified into three groups: Tubers weighing 200 to 300 g or tubers with a diameter equal or bigger than 60 mm, Tubers weighing 80 to 200 g or tubers with a diameter ranging between 30 and 60 mm, and tubers weighing less of 80 g or tubers with a diameter that is less than 30 mm. The number and weight of tubers of each category and for each variety were determined. The category one and two were classified in marketable yields while the last category was classified as unmarketable yields.

Processing test

This test consists of identifying the phenotypic characteristics of processing qualities such as shape, type and number of eyes using visual inspection. The dry matter was determined using under-water weight methods as detailed by Haase (2004). The Ashton Mayer's tool was set to zero. Potato sample was put in bags, determined the weight in air, and record the results. Eighty liters of water were filled in an open tank and float the weighed potato in air. The potato samples in bag were dropped until down of tank and reset tools to zero. Bags of samples were kept suspended in water and read the number in ashton Mayer's tool. Weight of samples in water was recorded using the following Formula 1 and 2:

$$\text{Sp.gr} = [\text{weigh in air} / (\text{weigh in air} - \text{weigh in water})] \quad (1)$$

$$\text{Dry matter (\%)} = [24.182 + 211.04 (\text{sp.gr} - 1.0988)] \quad (2)$$

Other processing characteristics such as frying time, color (sugar content), taste, crunch, waste, conversion, and others were tested by WINNAZ, a processing factory. The sugar content was assessed using color chart after frying (Bonierbale et al., 2006).

Data analysis

Data collected were processed by analysis of variance (ANOVA) using GenStat 15th edition. When the significance of differences among genotypes, sites, and seasons were detected, the mean separation was performed with the Least Significant Difference (LSD) test (P = 0.01 and P= 0.05) (Payne et al., 2011). The qualitative data (such as disease and pests score, and plant vigor) were processed by determining their averages using SPSS (PASW statistics 18.0) computer package (SPSS, 2006), and Microsoft Excel (Windows Office 2012; Microsoft Inc., Redmond, WA).

RESULTS

Yield results

Effects of variety, site, season, and interactions of variety × season, site × season, and variety × site × season on marketable yields of potato were significant. However, the interaction of varieties × site was not significant (Table 2).

The CIP varieties showed the highest marketable yields compared to Dutch varieties (Table 2). The yield of these varieties was 28 and 22.8 tons ha^{-1} for Kirundo and Kinigi, respectively. The highest yielding of marketable tubers among tested Dutch varieties were Panamela with 17.5 tons ha^{-1}, Rosi with 13.6 tons ha^{-1}, Taurus with 13 tons ha^{-1}, Sagita with 12.9 tons ha^{-1}, and Deby with 12.5 tons ha^{-1}. The lowest yielding among tested Dutch varieties were Challenger with 9 tons ha^{-1} and Fabula with 8.4 tons ha^{-1} (Table 3).

Variety, site, season, and interactions of variety × season, site × season, and variety × site × season showed significant effects on total yields of potato. The interaction effects of variety × site on total tuber yields were not significant (Table 4).

The average total yields of CIP varieties were extremely high and significantly different compared to tested Dutch varieties. These yields were 34.2 and 30.7 tons ha^{-1} for Kirundo and Kinigi, respectively. The best performing among tested Dutch varieties were Panamela with 20.2 tons ha^{-1}, Rosi 16.4 tons ha^{-1}, Sagita with 15.8 tons ha^{-1}, and Taurus with 14.4 tons ha^{-1}. The lowest yielding among Dutch tested varieties were Fabula with 11.6 tons ha^{-1} and Challenger 13.5 tons ha^{-1} (Table 5).

Plant vigour, diseases and pest results

The CIP varieties Kinigi and Kirundo (both with a score of 7.2) revealed a big plant vigour compared to tested Dutch varieties. Among the Dutch varieties, Taurus and Panamela with scores of 6.9 and 6.2, respectively,

Table 2. Analysis of variance for marketable yields of CIP and Dutch potato varieties tested at three sites for two growing seasons in Rwanda.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	142.47	71.23	2.86	-
Varieties	10	6348.28	634.83	25.48	<0.001
Site	2	4322.15	2161.07	86.72	<0.001
Season	1	2631.59	2631.59	105.6	<0.001
Variety × Site	20	649.14	32.46	1.3	0.189
Variety × Season	10	779.34	77.93	3.13	0.001
Site × Season	2	3257.37	1628.68	65.36	<0.001
Variety × Site × Season	20	1107.98	55.4	2.22	0.004
Residual	130	3239.53	24.92	-	-
Total	197	22477.85	-	-	-

Table 3. Average of marketable yields (tons ha^{-1}) of potato varieties tested for two growing seasons at three sites in Rwanda.

Variety	Cyanika		Cyuve		Mudende		Average
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	
Challenger	4.0	4.4	16.0	4.4	20.9	4.4	9.0^{d}
Derby	6.3	6.6	23.7	6.3	28.0	4.4	12.5^{cd}
Fabula	3.3	4.3	8.9	4.5	19.2	10.2	8.4^{d}
Kinigi	13.2	19.0	24.3	22.9	29.7	27.8	22.8^{ab}
Kirundo	11.3	22.9	38.3	21.5	47.2	26.6	28.0^{a}
Memphis	5.9	7.1	12.2	8.7	27.0	10.7	11.9^{d}
Panamela	6.9	15.4	21.5	13.1	35.4	12.7	17.5^{bc}
Rosi	5.3	8.0	17.5	8.8	34.4	7.3	13.6^{cd}
Sagitta	5.3	8.5	26.0	5.0	25.0	7.8	12.9^{cd}
Sifra	5.6	10.3	13.9	6.2	20.1	13.0	11.5^{d}
Taurus	6.9	10.4	23.6	7.0	16.9	13.0	13.0^{cd}
% CV	-	-	-	-	-	-	15.7
LSD (0.05)	-	-	-	-	-	-	8.1

Table 4. Analysis of variance of total yields of CP and Dutch potato varieties tested at three sites for two growing seasons in Rwanda.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	16.26	8.13	0.3	-
Varieties	10	10085.99	1008.6	37.24	<0.001
Site	2	1308.99	654.5	24.16	<0.001
Season	1	6466.97	6466.97	238.75	<0.001
Variety × Site	20	773.21	38.66	1.43	0.121
Variety × Season	10	631.22	63.12	2.33	0.015
Site × Season	2	304.64	152.32	5.62	0.005
Variety × Site × Season	20	1012.34	50.62	1.87	0.02
Residual	130	3521.3	27.09	0	0
Total	197	24120.93	0	0	0

showed the highest plant vogour. The Dutch variety showing the lowest plant vigour was Fabula with a score of 3.9 (Table 6). According to the late blight score, the CIP varieties Kinigi and Kirundo, and Dutch varieties Sifra

Table 5. Average total yields (tons ha^{-1}) of CIP and Dutch potato varieties tested for two growing seasons at three sites in Rwanda.

Variety	Cyanika		Cyuve		Mudende		Average
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	
Challenger	12.2	6.8	21.7	6.6	26.3	7.3	13.5^{c}
Derby	16.6	8.2	18.3	7.8	27.0	6.2	14.0^{c}
Fabula	16.4	5.7	12.1	4.4	21.6	9.3	11.6^{c}
Kinigi	43.0	21.2	27.5	21.6	39.7	31.4	30.7^{a}
Kirundo	37.1	23.9	39.8	25.1	51.4	27.8	34.2^{a}
Memphis	16.7	8.0	15.2	8.6	25.5	10.5	14.1^{c}
Panamela	22.2	15.2	22.7	11.9	30.7	18.4	20.2^{b}
Rosi	14.2	10.8	22.5	8.1	33.2	9.8	16.4^{bc}
Sagitta	19.6	9.5	30.9	6.6	19.7	8.7	15.8^{bc}
Sifra	11.6	10.7	12.3	8.1	23.3	16.2	13.7^{c}
Taurus	12.8	11.2	21.3	8.0	19.2	14.0	14.4^{c}
% CV	-	-	-	-	-	-	12.7
LSD (0.05)	-	-	-	-	-	-	8.5

Table 6. Plant vigor, late blight, virus, and leaf miner score of CIP and Dutch potato varieties tested for two growing seasons at three sites in Rwanda.

Variety	Vigour	Late blight score	Virus score	Leaf miner
Challenger	4.6	7.2	2.9	5.7
Derby	4.6	7.0	2.2	4.8
Fabula	3.9	7.0	2.2	4.1
Kinigi	7.2	3.0	3.1	3.9
Kirundo	7.2	2.3	1.2	2.8
Memphis	5.9	6.6	2.8	5.7
Panamela	6.2	4.2	1.4	2.9
Rosi	5.2	7.0	2.4	5.0
Sagitta	4.8	5.2	2.0	3.4
Sifra	5.7	2.9	2.6	3.2
Taurus	6.9	3.1	2.6	3.3

and Taurus revealed the same trends. Their late blight score was below 3 (less than 30% of plants revealed late blight symptoms) (Table 6). For virus diseases of both varieties, the score was not exceeding 3, meaning that less than 50% of foliage area of plants revealed viral symptoms (Table 6).

Processing results

The potato with high number of deep eyes was only a CIP variety Kinigi. The other varieties revealed a low number of shallow eyes (Table 7). In terms of dry matter content, Taurus, Challenger, and Panamela revealed the highest dry matter content of 22.4, 21.7%, and 20.0%, respectively. This dry matter content is high compared to CIP variety Kinigi with a dry matter content of 19.20%. Results obtained after frying (Conversion, time for frying, color, taste, and crunch) are presented in Table 6.

Based on colour and rolling of processed chips, the Dutch varieties Rosi, Challenger and Taurus revealed crisps with clear yellow color without rolling. Panamela and Kinigi showed crisps with similar characteristics (Figure 1).

DISCUSSION

Yields

Adaptability of crop varieties can vary from location to location depending on the agro-ecology of a particular area. The development and dissemination of best suited varieties with specific adaptability to the environment was

Table 7. Results of processing test of nine Dutch potato varieties and one local variety, Kinigi.

No.	ID Clone	Shape (ovale)	Eyes type	Eyes number	sp.gr	DMC (%)	Conv	Frying time (s)	Colour	Taste	Crunch	General observations
1	Sifra	long	shallow	few	1.05	13.88	4.50	208	6.00	bad	bad	bad
2	Memphis	long	shallow	few	1.08	20.21	10.00	230	2.50	bad	bad	bad
3	Sagitta	long	shallow	few	1.06	15.99	5.00	251	3.50	bitter	bad	bad
4	Panamela	long	shallow	few	1.08	20.21	53.60	194	4.50	good	bad	bad
5	Derby	long	shallow	few	1.06	15.99	5.00	235	3.50	bad	good	bad
6	Rosi	round	shallow	more	1.07	18.10	3.90	270	2.00	good	good	good
7	Challenger	round	shallow	more	1.09	22.32	6.70	190	2.00	good	good	good
8	Taurus	round	shallow	few	1.09	22.32	6.70	236	2.00	bad	good	good
9	Fabula	round	shallow	more	1.06	15.99	4.30	235	3.00	bad	bad	bad
10	Kinigi	round	deep	more	1.08	20.21	4.10	270	2.50	good	good	good
11	Kirundo	-	-	-	-	-	-	-	-	-	-	-

Conv: Conversion, DMC: dry matter content, s: second.

Figure 1. Crisps processed by WINNAZ from Kinigi (a CIP potato variety) and nine Dutch potato varieties.

a sustainable strategy to increase the productivity and production, and to overcome economic and food security constraints. Therefore, it is essential to carry out specific adaptation trials to identify suitable varieties. In the evaluation of potato varieties at Bule Hora District, in Ethiopia, Addis et al. (2017), found a significant variation among potato varieties for tuber yields, number of tubers per hill, and tuber weight per hill. Statistical analysis of the dry matter content, and starch yields of various tested potato varieties revealed significant effects ($P < 0.01$) due to genotype, location variation and genotype × environment interaction. The dry matter content and starch yields ranged from 17.82 to 26.70% and from 2.21 to 6.91 %, respectively (Tesfaye et al., 2012). Habtamu et al. (2016) reported statistically significant variations in most of evaluated traits. The highest total yields of 56.52 tons ha^{-1} and marketable tuber yield of 53.97 tons ha^{-1} were observed. The results from this study agreed with these previous findings. Effects of variety, site, season, and interactions of variety × season, site × season, and

variety × site × season on marketable and total yields of potato were significant. The interaction effects of variety × site on total tuber yields were not significant (Tables 2, 3 and 4).

Marketable yields are an important trait for root and tuber crops because it is sold on market to get money while no marketable yield is mainly used by farmers for home consumption. This yields category is affected by different factors. For example, at the wider intra row spacing of 30 cm, and at the closer intra row spacing of 10 cm, the marketable tuber yields were 23.54 and 18.27 tons ha^{-1}, respectively. The highest marketable tuber yields of 27.48 tons ha^{-1} were obtained at the 15 days earthing up whereas the lowest yield of 17.03 tons ha^{-1} was obtained at the 45 days earthing up (Getachew et al., 2012). Through this study, the check varieties are adapted to local environmental conditions. Therefore, their average total yields were extremely high and significantly different compared to Dutch varieties under evaluation. These yields were 34.2 and 30.7 tons ha^{-1} for Kirundo and Kinigi, respectively. The best performing among tested Dutch varieties were Panamela with 20.0 tons ha^{-1}, Rosi with 16.0 tons ha^{-1}, Sagita with 15.0 tons ha^{-1}, and Taurus with 14.4 tons ha^{-1}. The lowest yielding among Dutch tested varieties were Fabula with 11.6 tons ha^{-1} and Challenger with 13.5 tons ha^{-1}. The same varieties have showed the same trends of marketable yields (Tables 4 and 5). These findings highlights that the tested varieties, the two growing seasons and the sites where potato varieties were tested are different. The tested varieties have a different genetic makeup. The sites where the trials were conducted have different soils characteristics, mico-climates. Also, the two growing seasons in which potatoes were tested are different. For example, the season A (September to December) is characterised by a heavy and long lasting rainfall, while the growing season B (March to June) is characterised by light and short lasting rainfall. These variations are the main causes of variations in marketable and total yields observed among tested potato varieties. Even though two seasons are recommended for National Performance Trials to evaluate new potato varieties released in COMESA region, the carried out trials did not reveal the trends of stability and adaptability of tested Dutch varieties. Therefore, the conclusion made is only based on yield across all seasons and sites.

The Dutch varieties are new in the Rwandese environmental conditions. This is the main reason their yields were low compared to local check varieties. This was also confirmed by diseases results (Table 6), where, the Dutch varieties revealed a high susceptibility to late blight. All tested plant materials (Dutch varieties and local check varieties) were treated in the same conditions but only two Dutch varieties Sifra and Taurus revealed the lowest disease score as Kinigi and Kirundo, the local checks. Others Dutch varieties were extremely susceptible to late blight (Table 6). Even though, an extreme susceptibility was observed, the results revealed that by using special approaches for diseases control, the Dutch varieties such as Panamela, Sagita, Taurus and Rosi can produce appreciable yields as local varieties. However, these approaches have implications on the cost of potato production. Consequently, the selling price of the yields should be high compared to local varieties, because the local varieties can produce enough yield without special disease control approaches.

Plant vigour, diseases and pest results

The CIP varieties Kinigi and Kirundo (both with a score of 7.2) revealed a big plant vigour than Dutch varieties under evaluation. Among the Dutch varieties, Taurus and Panamela with scores of 6.9 and 6.2, respectively, showed the highest plant vogour. The Dutch variety showing the lowest plant vigour was Fabula with a score of 3.9 (Table 6). The Dutch varieties were developed in long day environments while the CIP varieties were developed at Lima, Peru within a short day environment. Trials were established in Rwanda where there is a short day environment. Therefore, the low plant vigor observed on Dutch varieties compared to CIP varieties should be associated with the day length. This has effects on variation of yield between these categories of potato varieties (Dutch and CIP varieties). It is known that the leaf canopy is the center of photosynthesis which produces plant assimilates for tuber formation. Canopy structure and vigor, reduce weeds and soil water evaporation. Farmers perceive that the crop varieties with high plant vigor produce high yield. However, this yield is associated with the genotype photosynthesis capacity. The same observation was reported by Pereira et al. (2017), in their study to identify the performance of advanced potato clones, plant vigor, tuber yield and specific gravity of Brazilian and European potato varieties. They found that under Brazilian soil and climate conditions, yields of European varieties are lower in comparison with the countries of origin, because these cultivars were selected under long photoperiod and low pressure conditions of some biotic factors affecting the crop in Brazil. Silva et al. (2014), reported that when best European varieties are cultivated under subtropical and tropical conditions, they show a shorter vegetative period, and, therefore, have a lower photoassimilate production. They suggested that it is necessary to use a large quantity of inputs to achieve higher yields, but this may lead to lower crop sustainability.

Processing qualities

Potato processing industries require continuous supply of tubers as raw materials for fries or crisps preparation (Adnan et al., 2016). Currently the most important

characteristics of potato production is processing quality. This is because farmers want a high price of their produce and consumers wants to facilitations in food preparation, by buying processed products. Potato supply as a raw material for processing industry must fulfil a number of qualities including low sugar contents, high dry matter, more specific gravity, high antioxidants, low weight loss, good color, and shallow eyes (Connor et al., 2001). Therefore, there is a need to develop and evaluate the processing characteristics of different commercial potato cultivars for the benefit of chips and crisps industries (Adnan et al., 2016). The results from the present study revealed that the potato with high number of deep eyes was a CIP variety Kinigi. The others varieties revealed a low number of shallow eyes (Table 7). In terms of dry matter content, Taurus, Challenger, and Panamela revealed the highest dry matter content of 22.4, 21.7, and 20.0%, respectively. This dry matter content is high compared to CIP variety Kinigi with a dry matter content of 19.20% (Table 7). Based on colour and rolling of processed chips, Dutch varieties Rosi, Challenger and Taurus revealed crisps with yellow color without rolling. Panamela and Kinigi showed crisps with similar characteristics (Figure 1). All tested Dutch varieties revealed the shape, type and number of eyes appropriate for processing varieties. These varieties have low number of shallow eyes (Table 7). At this point, the CIP variety Kinigi does not have these characteristics; its eyes are extremely deep. The dry matter content is very important characteristic for roots and tubers varieties for processing. However, this trait is significantly affected by the environment (Elfnesh et al., 2011; Abebe et al., 2012). This study revealed that Dutch varieties such as Taurus with a dry matter content of 22.4% Challenger with a dry matter content of 21.7%, and Panamela with a dry matter content of 20.0% revealed the highest dry matter content, compared to CIP variety Kinigi with a dry matter content of 19.20%, commonly used for French fries and crisps (Table 6). This indicates that Dutch varieties can produce tubers with enough dry matter content meeting the processor needs. Based on taste, conversion, and crunch (Table 7) and on rolling and colour of processed crisps (Figure 1), the Dutch varieties such as Rosi, Challenger and Taurus were the best to give quality crisps. Panamela and Kinigi showed crisps with similar characteristics. Therefore, any private company planning to invest in potato processing, the aforementioned varieties are good candidates for crisps and chips.

Conclusions

Two growing seasons of National Performance Trials of a new varieties released in one country of COMESA region, are recommended if a breeder wants to release these varieties in another country of the same region. The results from the established National Performance Trials did not reveal the trends of stability and adaptability of tested varieties. The Dutch potato varieties like other European grown varieties were selected in conditions of long photoperiod and low biotic and abiotic stresses. When these varieties are grown under tropical conditions, with a short photoperiod and high biotic and abiotic stresses, they showed a low photo assimilate production, highly susceptibility to the late blight, a low plant vigour, and yields compared to other potato varieties like CIP varieties developed in these conditions. Therefore, the cultivation of these Dutch varieties requires to use a special input to achieve higher yields, but this may lead to lower crop sustainability and negative implications on the cost of production. The Dutch varieties namely Panamela, Sagita, Taurus and Rosi can produce appreciable yields as CIP varieties if special measures are applied. Among tested varieties, the Dutch varieties of Rosi, Challenger and Taurus are the best to produce crisps, while Panamela produces crisps with similar characteristics as CIP variety Kinigi, commonly used for French fries and crisps. Therefore, any private company planning to invest in potato processing for French fries and crisps in Rwanda, the Dutch varieties of Rosi, Challenger, Taurus, and Panamela are good candidates to produce raw materials.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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