"Field performance of CIP potato clones in contrasting environments in Burundi"

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ABSTRACT

Potatoes (Solanum tuberosum L.) have been grown for decades for home consumption and commercial use in highlands of Burundi where temperature is lower than in the lower lands. All attempts to introduce them in the lowlands of Burundi failed because the material tested always appeared not to be suitable to this hot environment with regard to tuber yield and other agronomic characteristics. A set of 15 potato genotypes presented as more tolerant to high temperatures was hence introduced in 2004 from the International Potato Center (CIP) and tested together with nine local varieties in various environments for three years. From the coolest environment (16.9°C) to the hottest one (26°C); fresh tuber yield, dry tuber yield, tuber dry matter concentration and harvest index decreased significantly. However, combined analysis indicated that, if heat tolerant cultivars are grown in the lowlands of Burundi, a fresh tuber yield of 13 t ha-1 or more should be expected whereas a non suitable cultivar like Ndinamagara (Cruza 148) would produce only 2.7 t ha-1. Contrary to what was expected, an early maturing variety (Victoria) and a late maturing clone (395194.9) performed satisfactorily in both cool (highlands) and warm conditions. Four clones (390663.8, 395194.9, 388972.22 and 388611.22) and one variety (Victoria) were found to be the most suitable for the Imbo region (warm areas). Furthermore, the hot climate negatively influenced the tuber set, and therefore, tuber number was lower (23.3 tubers per plant in highlands and 7.1 in lowlands). The agronomic implication is that the Imb...

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Field performance of CIP potato clones in two contrasting environments in Burundi

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Abstract Potatoes (Solanum tuberosum L.) have been grown for decades for home consumption and commercial use in highlands of Burundi where temperature is lower than in the lower lands. All attempts to introduce them in the lowlands of Burundi failed because the material tested always appeared not to be suitable to this hot environment with regard to tuber yield and other agronomic characteristics. A set of 15 potato genotypes presented as more tolerant to high temperatures was hence introduced in 2004 from the International Potato Center (CIP) and tested together with nine local varieties in various environments for three years. From the coolest environment (16.9°C) to the hottest one (26°C); fresh tuber yield, dry tuber yield, tuber dry matter concentration and harvest index decreased significantly. However, combined analysis indicated that, if heat tolerant cultivars are grown in the lowlands of Burundi, a fresh tuber yield of 13 t ha⁻¹ or more should be expected whereas a non suitable cultivar like Ndimamagara (Cruza 148) would produce only 2.7 t ha⁻¹. Contrary to what was expected, an early maturing variety (Victoria) and a late maturing clone (395194.9) performed satisfactorily in both cool (highlands) and warm conditions. Four clones (390663.8, 395194.9, 388972.22 and 388611.22) and one variety (Victoria) were found to be the most suitable for the Imbo region (warm areas). Furthermore, the hot climate negatively influenced the tuber set, and therefore, tuber number was lower (23.3 tubers per plant in highlands and 7.1 in lowlands). The agronomic implication is that the Imbo region could be appropriate for consumer potatoes but not economically appropriate for seed production. The seed could be multiplied in highlands and then brought to Imbo for commercial production. Despite the satisfactory fresh tuber yields obtained by these genotypes under high temperatures in comparison with other genotypes or the average national potato yield reported to be 2.7 t ha⁻¹ by FAO, we believe that their potential was not achieved and higher yields could be obtained with better crop management. Therefore, there is need to carry out complementary studies on agricultural techniques aiming at increasing the yields obtained so far.

Key words: Agro-physiological characteristics, Burundi, highlands, potato genotypes, warm areas

Introduction

As in other developing countries, potato crop (Solanum tuberosum L.) is increasingly becoming a cash crop in Burundi. However, the national production estimated at 26,000 t year⁻¹ (FAO, 2008) is still low compared to the quantity required for feeding more than eight millions of people (Burundi_Tribune, 2009), mostly in the cities. Unfortunately, this gap is expected to grow bigger and bigger due to the increase in population and urbanisation. Therefore, three alternatives are possible to overcome this problem. The first scenario is to increase the productivity where potato is already grown. The second scenario is to introduce the crop where it has never been grown before such as in the hot micro-climates of the Imbo region. And the last way to solve the problem is to import potatoes from abroad. This study falls under the second scenario. Our overall goal is introducing potato crop in lowlands agrarian systems by determining the effects of temperature on main agro-physiological characteristics under field conditions. That is why we evaluated a couple of CIP (International Potato Center) genotypes with expected potential for lowlands adaptability. Our objective in the long run is to be able to recommend to farmers and other stakeholders varieties to grow in the lowlands of the Imbo region.

Even if potato is not grown so far for consumption in lowlands, several trials have been conducted there since 1989 by ISABU scientists (ISABU, 1989; ISABU, 1990; ISABU, 1993) and students from University of Burundi (Furero, 2000; Mpfubusa, 2003). All those trials were carried out independent of each other. There was no coordination and the germplasm used differed among the trials. Moreover, the trials were also exclusively located in the same hot environment and comparison under the conditions of Burundi with regions at lower temperature was not possible. Also, yield data expressed in tuber fresh weight were not converted into dry matter production. Therefore, it was quite difficult to come out with clear answers to questions such as which genotypes to grow in Imbo region despite prevailing high temperatures. This study could be an answer to these questions.

Materials and Methods

Experimental sites. Three experiments were carried out in four locations and through three years: Mugerero (801 masl) and Mparambo (892 masl) situated in lowlands,
Gisozi (2091 masl) and Ryansoro (1833 masl) located in the highlands. The first experiment was conducted in 2005 in Mugerero (lowlands). The second experiment (2006) was conducted in two sites: in Mparambo but also on the same site as in 2005 in Mugerero. Conducted in 2007, the last experiment was carried out in multi location trials involving both highlands (Gisozi and Ryansoro) and lowlands (Mparambo). During the whole study, the average temperature in lowlands (Mparambo and Mugerero) ranged from 24.4 to 26°C whereas in the highlands it ranged from 16.9 (Gisozi) to 19.4°C (Ryansoro). Within the same period, the maximum temperature in highlands was always less than the average temperature found in lowlands. The maximum temperature ranged from 29.7 to 31.1°C in lowlands against 23.8 and 22.5°C at Ryansoro and Gisozi, respectively. In highlands, the average annual rainfall is around 1400 mm against 900 mm in lowlands. All trials were installed during the dry seasons. That is why furrow irrigation was applied in lowlands at one-week interval and not in highlands where we planted in marshlands (with shallow water table).

**Genotypes used.** Out of 15 clones bred for hot climates by CIP and introduced in Burundi in 2004, five promising ones (CIP01, CIP02, CIP03, CIP04 and CIP05) were selected and planted in all our experiments. The CIP numbers for those genotypes are as follows: 388611.22 (CIP01), 388972.22 (CIP02), 390663.8 (CIP03), 395193.4 (CIP04) and 395194.9 (CIP05). For practical purpose, codes are hereafter used instead of CIP denomination. All of them are virus resistant potato clones safely kept at CIP headquarters for public access (CIP, 2008). In addition to clones, we also planted three varieties which were released in Burundi several years ago. These varieties are Ndynamagara (also called Cruza 148), Victoria (381381.20) and Ruhanyura (382171.4). In this study, these varieties are coded as follows: NDINA standing for Ndynamagara, RUHA for Ruhanyura and VICTO for Victoria. Unlike the two last varieties cited, NDINA is known to be a late maturing variety. It is also the most cultivated potato variety in the country. However, tubers of NDINA are not appreciated at the market, especially for chips consumers, due to the intrinsic vascular discoloration. A purple pigment is seen in the centre when a tuber is cut into two pieces thus, some people in the cities call this variety “Mauve”, meaning purple in French. This is an indicator of high content for anthocyanins in this variety as reported in literature (Storey & Davies, 1992). Introduced for the first time in 1998 (Harahagazwe, 2006), VICTO is the most popular variety in Uganda where it was released for the first time in September 1991 (Low, 1997). Due to its high yielding ability, RUHA was released for the first time at Buyengero (Harahagazwe, 2003). Table 1 describes briefly the genotypes used in the experiments.

These clones contain Ryadg gene from *S. tuberosum* ssp. *andigena* which confers extreme resistance to PVY (Bonierbale of CIP, personal communication). Clones are presented according to the descriptions given by the International Potato Center (CIP, 2008) while the varieties are described according to the Burundi National Potato Catalog (Harahagazwe, 2006).
Experimental design. Trials were conducted in a randomized complete block design (RCBD) with four replicates. Each plot contained 30 plants in two rows of 15 plants each. For both trials, we planted at 80 cm in-between rows and 30 cm between plants within rows, meaning a plant population density of 4.17 plants m\(^{-2}\). Cultivar NDINA was used as a crop border. Crop management for our trials was applied as normally recommended by the National Agricultural Research Institute (ISABU). In each planting hole, we put around 500 g of organic manure from cows. On average, we added in each hole 14.3 g of N-P-K fertilizer (595 kg ha\(^{-1}\)). This was equivalent to the application of 85 kg ha\(^{-1}\) of Urea, 340 kg ha\(^{-1}\) of DAP and 170 kg ha\(^{-1}\) of KCl which represents 100-150-100 units of N, P\(_2\)O\(_5\) and K\(_2\)O respectively. Plants were protected against late blight caused by *Phytophthora infestans* (Mont.) de Bary by spraying Ridomil Gold MZ 68WP and Dithane M-45 in an alternated manner. Dimethoate was also sprayed in order to control aphids.

Experimental data collection and analysis. Several parameters were recorded from the planting date to harvest time. The major parameters collected are listed as follows: emergence rate, ground cover, plant height, leaf area index (LAI), specific leaf area (SLA), tuber yield, tuber dry matter concentration and harvest index. We used a wooden grid divided into 100 rectangles, viewed from above while held in hand by two persons, when measuring the ground cover. For each plot, three plants were harvested in order to determine LAI using Imagel technology. At the same time, the samples were separated into different organs and then dried up in a laboratory using an oven at 105°C for 72 hrs so that we could calculate SLA, dry matter concentration and dry matter yield. Pests and diseases were assessed at every field visit. Although the fungicides were sprayed, late blight was observed on highlands on two genotypes. Therefore, its severity was visually measured as the percentage of diseased shoots (stems and leaves) in comparison to the entire healthy plants for each plot.

First, we analysed data per trial separately according to a RCBD model except for the dry matter concentration for which we ran the completely randomised block (CRB) design model because tubers were sampled at random without blocking (Gomez & Gomez, 1984). For a couple of variables, we analysed the genotypes versus environments data in a combined analysis of variance (ANOVA) over sites in which the block source of variance (error a) refers to blocks within environments (Gomez & Gomez, 1984).

In the combined analysis (ANOVA), treatment observation *Y*\(_{ger}\) - for genotype *g*, environment *e* and replicate *r* – is partitioned into (1) an additive model with three parameters, namely the grand mean *μ*, genotype deviation *α*\(_g\), and environment deviation *β*\(_e\), (2) the non-additive residual or interaction *θ*\(_{ge}\), and the error term *ε*\(_{ger}\) as follows (Gauch, 1992):

\[
Y_{ger} = \mu + \alpha_g + \beta_e + \theta_{ge} + \varepsilon_{ger} \tag{1}
\]

In case of significant (p<0.05) main effects (genotypes and locations) and interaction, we furthermore analysed in GenStat, the variability of genotypes over locations with an additive main effects and multiplicative interaction (AMMI) model, since it combines ANOVA and principal component analysis (PCA) into a single analysis by decomposing the non-additive residual or interaction of ANOVA (Equation 1) into PCA axes 1 to N (Equation 2), and a residual. In the PCA, part of the model after removing the grand mean estimated by \(\bar{y}\), the model uses eigen-analysis to partition a treatment observation *Y*\(_{ger}\) into (1) a multiplicative model with PCA axes 1 to N, (2) a residual, if not all PCA axes are used, and (3) the error as shown in the following equation (Gauch, 1992):

\[
Y_{ger} = \mu + \sum_{n} \lambda_n \gamma_g \eta_{en} + \rho_{ge} + \varepsilon_{ger} \tag{2}
\]

In this model, the multiplicative parameters are: \(\lambda_n\), the singular value for PCA axis *n*; \(\gamma_g\), the genotype eigenvector for axis *n*; and \(\eta_{en}\), the environment eigenvector for the same axis. In our analysis, we considered the PCA 1 model meaning that *n* = 1 (one interaction principal component). The AMMI model equation (equation 3), which combines ANOVA and PCA, is written as follows (Gauch, 1992):

\[
Y_{ger} = \mu + \alpha_g + \beta_e + \sum_{n} \lambda_n \gamma_g \eta_{en} + \rho_{ge} + \varepsilon_{ger} \tag{3}
\]

The most attractive attribute of AMMI is that it generates a biplot consisting of means versus interaction PCA1 (IPCA1) which displays both the mean variable and interaction scores of the genotypes and environments on a single plot (Gauch, 1992; Gauch, 2006; Tai, 2007). Reading this biplot requires knowledge of its interpretative principles. Among symbols of the same kind either for genotypes or for environments, displacements along the X Axis indicate differences in main (additive) effects, whereas displacements along the Y Axis reveal differences in interaction effects. On the other hand, for the symbols of different kinds, the AMMI model provides the expected variable value. The main effects for genotypes reflects breeding advances while the main effects for environments express the overall site quality (Gauch, 1992). However, when a genotype is closer to an environment on the biplot, it does not mean that the genotype is superior in that environment (Gauch, 1992; Yan & Kang, 2003).

Results

Haulm characteristics. The seed used was in a good physiological state and all experiments showed high emergence rates. In general, all the genotypes emerged well in all environments except RUHA which showed significantly (p<0.05) lower emergence than the other ones in the following environments: Gisozi (51.7 %) and Ryansoro (86.7 %) for highlands and Mpambiro 2006 (28.3 %) for lowlands. Therefore, this variety had the lowest
emergence rates in all altitudes (Fig. 1A). This may be explained by its genotypic background (Harahagazwe, 2006).

After emergence, some genotypes produced very tall plants in highlands like NDINA (79.6 cm in Gisozi) and in lowlands such as CIP01 (67.9 cm in Mparambo 2007) and RUHA (65.8 cm in Mparambo 2007) while CIP03 proved to be small (44.8 cm in Gisozi) especially in highlands (Fig. 1B). The response of plant height to the environment (temperature) differed among genotypes. CIP01, CIP03 and VICTO became taller when the temperature rose from highlands to lowlands (Fig. 1B) even if the plants were generally tall in highlands. As discussed later in this paper, these three genotypes belong to the best genotypes group in terms of tuber yield and components in lowlands, meaning a possible relationship between the variables for this particular material. The positive relationship between the plant growth (plant height) and temperature has been reported in various studies (Benoit et al., 1986; Wolf et al., 1990).

From highlands to lowlands, ground cover for all genotypes decreased significantly (p<0.001) as shown in Figure 1C. The best genotypes for ground cover in highlands (Gisozi) turned out to be NDINA (92.3 %), CIP05 (91.1 %), VICTO (90.2 %), CIP04 (84.6 %) and CIP02 (84.5 %; Fig. 1C). In lowlands, the following genotypes gave good ground cover; CIP01 (58.3 %), CIP05 (54.7 %) and VICTO (53.1 %).

In highlands, the inoculum of Phytophthora infestans (Mont.) de Bary causing late blight was so high that CIP03 and CIP04 did not respond to chemical sprays. Three months after planting, shoots of these genotypes were damaged up to 75 % in all plots at Ryansoro. In the same area, bacterial wilt caused by Ralstonia solanacearum yabuuchi was observed on some genotypes: NDINA (0.8 %), CIP03 (0.5 %) and RUHA (0.3 %). In lowlands, Fusarium wilt was the most important disease. Fortunately, all genotypes did not show the same level of susceptibility as the difference between them was significant (p<0.001). The most susceptible genotype was CIP02 with 25 % of wilt. Other genotypes followed in this order: RUHA (12.8 %), CIP01 (11.7 %), VICTO (8.7 %), CIP03 (8.6 %), CIP04 (6.5 %), CIP05 (2.6 %) and NDINA (0.5 %). In general, visual observations showed that plants were more diseased in lowlands than in highlands independent of the type of genotype or disease.

**Tuber yield and components.** Genotypes CIP05 and NDINA showed a high potential in terms of number of tubers produced. In high altitude (Gisozi and Ryansoro), they produced respectively an average of 37.2 and 32.8 tubers plant⁻¹ across the two sites. On the contrary, CIP03 and CIP04 produced less tuber number than the rest of the genotypes in highlands, the most suitable environment for tuber set. In lowlands, CIP05 produced up to 10 tubers plant⁻¹, all trials included (Fig. 2A). In the same environment (lowlands), tuber set for the remaining genotypes ranged from five (CIP04) to eight (CIP01, NDINA and VICTO) tubers plant⁻¹.

Comparison between genotypes showed that CIP03 and CIP04 produced large tubers across all environments tested weighing 55.5 and 49.3 g each, respectively. Even in lowlands where tuber size was expected to decrease, these clones produced large tubers measuring up to 54 and 50.1 g tuber⁻¹, respectively. CIP05 and NDINA produced small tubers in all environments and thus, had a small proportion of big size tubers especially in highlands (Gisozi) where their tubers were significantly different (smaller) from tubers of other genotypes (Fig. 2B). In this particular environment, only 24.4 % of tubers produced by CIP05 were larger than 40 mm against 26.5 % for the variety NDINA (Fig. 2C). In lowlands, tubers of these two genotypes remained smaller compared to other genotypes especially for NDINA (12.1 %) even if the rate of CIP05 was slightly higher than the one obtained in highlands (30.7 %).

We found a highly significant linear regression (r²=0.881 *** ) between the tuber weight and the proportion of big size tubers (Fig. 3A) as expected when Figure 2B and C are compared each other.

In general, the material used in our experiments performed as well as what is normally found in the Eastern and Central Africa in terms of dry matter concentration. In Kenya, for example, potato dry matter concentration varied...
Figure 2. Average tuber yield of experiments conducted from 2005 to 2007: tuber number plant$^{-1}$ (A), fresh tuber weight (B) and proportional number of big size tubers (C). Abbreviations and comments are as in Figure 1.

Figure 3. Estimated linear relationship between fresh tuber weight and proportion of big size tubers across environments versus genotypes (A) and relationship between tuber weight and tuber number per plant across locations from the multi location experiment conducted in 2007 (B). Letter n represents the eight potato genotypes means for three locations and four replications within location.

from 19.5% with cultivar Kenya Karibu to 21.3% with cultivar Kenya Mavuno (Lung’aho et al., 2006). In our experiments, two clones (CIP05 and CIP04) showed very high tuber dry matter concentration across all environments; 21.4 and 20.4% respectively. They were always members of the group of the best genotypes except in Ryansoro (highland) where CIP05 was better than any other genotype (Fig. 4A). Clone CIP03 was third with a dry matter concentration of 19.6%. In the same conditions, variety RUHA appeared to contain more water than other genotypes in most environments (Gisozi, Mparambo 2006 and Mparambo 2007). Even in Ryansoro, it had the lower dry matter concentration in the group of genotypes with lower dry matter. Furthermore, the mean per region (highlands or lowlands) of this variety did not reach the 18% of dry matter concentration required for human consumption (Woolfe, 1987) as clearly illustrated by Fig. 4A. The same figure shows that all genotypes reached the international standard except the varieties used (NDINA, RUHA and VICTO) when grown in lowlands. For example, tubers of NDINA contained 16% of dry matter in lowlands when all seasons were considered. More interestingly, all those clones appeared to be higher yielding than NDINA and RUHA with a minimum difference of 1.0 and 0.6 t ha$^{-1}$ of tuber dry matter, for the two latter genotypes respectively.

Potatoes and other Andean tubers are known to be highly productive species due to their harvest index (Condori et al., 2008), even higher than other species of worldwide importance used for food including grains and oil-seed crops (Kooman, 1995). However, this harvest index (HI) is variable. In highlands, lower values of HI were obtained with varieties, NDINA and RUHA. NDINA, whose HI was 0.18 in Mparambo 2007 (lowland) and 0.24 for all seasons conducted in lowlands, appeared to be the last one on the list in terms of HI value when grown in lowlands, together with CIP02 (Fig. 4B). On the basis of the standard errors of differences between the genotypes means, all genotypes were efficient in allocating assimilates to tubers in highlands with an average harvest index of 0.86, except three of them (RUHA, CIP05 and NDINA), whose average index was 0.75 only.

In highlands (Gisozi and Ryansoro), four genotypes were always among the best ones for fresh and dry tuber
yield (Fig. 5A and B). Those genotypes are CIP02, CIP05, VICTO and NDINA. In lowlands, NDINA lost its yield performance (8.0 t ha\(^{-1}\) of dry matter in highlands versus 1.1 t ha\(^{-1}\) in lowlands 2005), whereas CIP01, CIP02, CIP03 and CIP05 were part of the best genotypes in three out of four environments (location x year) representing lowlands. For example, CIP03 produced up to 2.5 t ha\(^{-1}\) of tuber dry matter in this environment, all seasons combined.

**AMMI analysis.** On the basis of AMMI analysis carried out on several parameters, two genotypes were noted to have an outstanding behavior. Clone CIP05 showed to be potentially more performing than the other genotypes on the AMMI biplots (Fig. 6). In all tested environments, except for Mparambo 2006 which was affected by floods, this clone was always among the best genotypes (not statistically different from the best genotypes according to the standard errors of differences between the means), for the following parameters: fresh and dry tuber yield, dry matter concentration and tuber number per plant. It is outstanding to find a late maturing genotype, CIP05, to remain performing in hot conditions because the opposite is common due to the short duration of the growth cycle (He et al., 1998; Spitters, 1987). Furthermore, this clone took first rank in tuber number (18.8 tubers plant\(^{-1}\); Fig. 6A), dry matter concentration (21.4%; Fig. 6C) and dry tuber yield (4.9 t ha\(^{-1}\); Fig. 6E). However, the large number of tubers produced by CIP05 was compensated by the small size of tubers (26.3 g each on average) as shown on Fig. 6B. According to this figure, the small tuber size of CIP05 is not expected to change over environments due to its lower IPCA1 score in absolute value obtained with the AMMI analysis.

The second outstanding genotype is variety VICTO. Figure 6E shows this genotype has IPCA1 score closer to zero with regard to dry tuber yield, meaning that it is less susceptible to interaction with environment. This variety performed similarly as late maturing genotypes (NDINA and CIP05) for most of parameters studied in highlands (cool environment) despite its early maturing trait. This stability of VICTO was already reported in the Democratic Republic of Congo for fresh tuber yield (Mutombo et al., 1998).

![Figure 4](image.png)

**Figure 4.** Average tuber dry matter concentration (A) and harvest index (B) of experiments conducted in 2005 and 2007. Abbreviations and comments are as in Figure 1. Horizontal line (A) represents the international dry matter concentration standard (Woolfe, 1987).

![Figure 5](image.png)

**Figure 5.** Average fresh (A) and dry (B) tuber yield of experiments conducted from 2005 to 2007. Abbreviations and comments are as in Figure 1.
Thus, these two genotypes can be expected to have a relatively stable behavior across environments. Their adaptability is wide and they may be planted in more environments than others. Also, less preliminary studies are needed before recommending them in new locations but with similar environments. However, in the case of uncontrolled conditions of late blight, VICTO is susceptible to this disease according to regional literature (Kankwatsa et al., 2002; Kankwatsa et al., 2003; Mulema et al., 2008; Namanda et al., 2004). This limits the situations where VICTO may be recommended as an outstanding genotype.

With regard to the harvest index, four genotypes seem to have the same and promising behavior if we look at biplot presented in Figure 6F. Those genotypes are CIP01, CIP03, CIP04 and VICTO. Across all environments, their average harvest index was 0.64. The implication of this statement is that those genotypes are genetically equipped to provide a good tubers/total biomass ratio wherever they are grown.

**Discussion**

In highlands, NDINA and CIP05 performed very well for most of the studied agro-physiological parameters. For example, both NDINA and CIP05 produced in Gisozi 0.91 kg m$^{-2}$ of tuber dry matters. In experiments carried out in Rwanda, Tunisia and The Netherlands, the highest dry
tuber yield was found at Wageningen in The Netherlands. It ranged from 1.02 to 1.63 kg m\(^{-2}\) (Kooman et al., 1996a). In our experiments, the performance of NDINA and CIP05 may be explained by their late maturation even if quantitative data on growth cycle are not presented in this study. It is indeed known that the length of the growth cycle is a crop characteristic which affects markedly the total dry matter production and thus, the dry tuber yield (Spitters, 1987; Kooman, 1995). The higher tuber yield of late maturing genotypes is associated to a more vigorous growth and to a longer duration of the photosynthetically active leaf area allowing a greater tuberisation during tuber bulking (Spitters, 1987; Kooman et al., 1996b; Silva, 2006). The two genotypes (NDINA and CIP05) were late maturing to the extent that the time of harvesting experiments was determined according to the end of their growth in all locations except in Mparambo where these genotypes were harvested before the final end of the cycle.

However, the two genotypes produced small tubers across all environments. This may be due to the large number of tubers produced per plant. There was a kind of compensation meaning that what was gained on one hand (tuber number) was lost on the other hand (tuber weight) and the two parameters were inversely related as commonly observed (Deblonde and Ledent, 2001). In fact, we found a strong negative linear regression \( r^2 = 0.905^{**} \) between these two parameters using the data from the multi location experiment conducted in 2007. The ability of CIP05 and NDINA to produce a lot of tubers comes from their genotypic background as already reported for the NDINA (Harahagazwe, 2006). Therefore, this small tuber size of NDINA and CIP05 could decrease their value on the market because the chips become smaller in comparison to big size tubers. This is in addition to the vascular discoloration of NDINA tubers.

The analysis of the relationship between tuber dry matter production per unit area and ground cover in the multi location experiment conducted in 2007 showed that the linear regression was significant in highlands \( (p<0.001) \) and across all sites \( (p<0.05) \). Figure 7 shows that the two regression lines are parallel meaning their respective slopes are the same. By increasing ground cover, an increase at the same time of tuber yield is expected. To achieve this, genotypes with high ground cover rates may be used but this may be also obtained through cropping practices like plant spacing. That is one of the explanations to the high yielding ability of CIP05. Its ground cover was among the highest across sites. However, tuber yield was only partly ground cover dependent with a coefficient of determination of 0.50. For example, in the multi location experiment conducted in 2007, dry tuber yield decreased from 7.9 to 2.5 t ha\(^{-1}\) [corresponding to a decrease of 68 % from highland (Gisozi) to lowland (Mparambo)] whereas ground cover decreased from 84.6 % (in highland) to 61.5 % (in lowland). Other factors like harvest index and hormonal system play a role. In hot conditions, gibberellins known to stimulate haulm growth while suppressing tuber production are found in stolon tips in high quantity in comparison with the growth inhibitors (Menzel, 1980).

Even if the overall means were low in lowlands \( (10.8 \text{ t ha}^{-1} \text{ of fresh matter}) \) due to limitation from high temperature, some genotypes performed quite well compared to the national average fresh tuber yield of 2.6 t ha\(^{-1}\) (FAO, 2008). If we highlight only two genotypes, clone CIP03 yielded 19.4 t ha\(^{-1}\) (equivalent to 3.8 t ha\(^{-1}\) in dry matter) and CIP05 produced 18.6 t ha\(^{-1}\) (equivalent of 3.5 t ha\(^{-1}\) in dry matter) in Mparambo 2007. In terms of fresh tuber yield, because potato yield is rarely expressed in dry matter in the regional studies, these clones produced almost three times as much as the best yield \( (6.8 \text{ t ha}^{-1}) \) obtained at Butole (1115 masl

![Figure 7. Estimated linear regression between tuber dry matter productivity and ground cover. Points in the graph are means variety \(^1\) in Gisozi (solid line) and across the three sites (dash line) of the experiment carried out in 2007. Letter \( n \) represents the number of potato genotypes evaluated. Symbols are means per genotype regardless the block or the site.](image-url)
of elevation) in Democratic Republic of Congo (Mutombo et al., 1998). Even in areas of Burundi where potato is traditionally grown, it is common to obtain lower yields than those produced in lowlands in our experiments with CIP03 and CIP05. The national potato yield given by FAO seems to be static since 2004 (FAO, 2008). Contrary to all expectations, this fresh yield is even much less than the 3.8 t ha\(^{-1}\) of dry tuber yield obtained from CIP03 in lowlands.

The combined analysis indicated that, if heat tolerant cultivars are grown in lowlands, a tuber yield ranging from 10 to 16 t ha\(^{-1}\) with an average of 13 t ha\(^{-1}\) should be expected whereas a non suitable cultivar like NDINA would produce 2.7 to 10.2 t ha\(^{-1}\) with an average of 6.7 t ha\(^{-1}\). The yields obtained in our tropical lowlands for the tested clones appear promising when it is compared to the average market yield in the United States of America, obtained under favorable conditions for the potato crop (Kooman, 1995). This national yield used to be 26 metric tonnes fresh weight of tubers ha\(^{-1}\) (Ku et al., 1977).

Amongst all genotypes tested, clone CIP03 performed quite well in many aspects when it was grown in lowlands. This early maturing and short clone was excellent in dry tuber yield, fresh tuber yield, weight per fresh tuber, dry matter concentration and harvest index across all environments. In addition, tuber set and dry matter did not vary so much from highlands (Gisozi) to lowlands (Mparambo) whereas fresh weight increased even up to 10 g tuber\(^{-1}\) considering results from the multi location trial conducted in 2007. This clone could be considered as the ideotype for this lowland environment. Thus, CIP03 appears to be more appropriate in lowlands than in highlands. However, CIP03 appeared to be very susceptible to late blight in highlands where strong chemical control was mandatory.

On the other hand, NDINA seemed to be the opposite of the CIP03 clone. As a tall and late maturing cultivar, NDINA was in lowlands very poor for many characteristics: fresh tuber yield, dry tuber yield, weight per fresh tuber, proportion of big size tubers, dry matter concentration and harvest index. Highly performing in highlands, NDINA is counter-productive when grown in lowlands. It should not be used there even if it showed to be less susceptible to *Fusarium* wilt than other genotypes. Because NDINA is the most commonly grown variety in the country since 1980’s, its use in lowlands by farmers may have completely discouraged them from any other initiative to test other genotypes. That could explain why potato is not grown so far in the Imbo region.

**Conclusion**

Findings of the study suggest that, in highlands of Burundi, the National Potato System should focus on six genotypes out of the five clones and three varieties we tested. Those genotypes are: CIP05, NDINA, VICTO, CIP04, CIP02 and CIP01 with special care to the first clone even if its tuber size is small. CIP03 and RUHA were less performing than the other genotypes. However, due to their high susceptibility to late blight, prophylactic measures should be taken when growing VICTO and especially CIP04 in this environment. In lowlands, the release program may start with four clones (CIP03, CIP05, CIP02 and CIP01). Variety VICTO should also be included. At the same time, use of NDINA or RUHA is not recommended in hot conditions. However, when growing potato in lowlands with genotypes listed above, special attention is required because *Fusarium* Wilt may compromise the yield and quality of tubers especially for susceptible material like CIP02 and CIP01.

Contrary to all expectations, CIP05 and VICTO appeared to be of adequate agro-physiological performance in highlands and lowlands despite a late and an early maturation for CIP05 and VICTO, respectively. This behavior may imply that the two genotypes can be grown in any environment within the ecological zones studied and that few preliminary tests would be necessary. But, when the inoculum pressure of late blight and/or *Fusarium* wilt is very high in the case of VICTO, more preliminary trials with control measures should be conducted.

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