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The potential of hybrid potato for East-Africa

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Abstract: Potato is an important staple crop in East Africa. Most of the seed tubers are propagated in informal systems, whereby the tubers become deteriorated and contaminated, resulting in low crop yields. Potato breeding has not resulted in significantly improved varieties that overcome these constraints. Recently, true potato hybrid breeding technology has been developed, whereby diploid hybrids are generated by crossing between homozygous inbred parent lines. The first series of experimental hybrids were pre-screened in The Netherlands and ten representative hybrids were tested in East-Africa, whereby the yield of the best hybrid was 29 ton/ha. These results show the great potential of hybrid potato for East Africa.

Keywords: Hybrid breeding, true seed, genetics, ploidy, cropping system, yield

1 Introduction

Potato is the world's third food crop for human consumption, and is grown all over the world. Breeding of new cultivars is done by national public institutes, by the international Potato Centre (CIP) or by private industries, mainly in Europe. Despite a growing worldwide number of more than 4000 cultivars (http://cipotato.org/potato/facts/), still very old varieties like Russet Burbank (introduced in 1876) in USA and Bintje (introduced in 1910) in Europe, are cultivated. The lack of genetic progress is also reflected in the lack of yield gain over the past century (Douches et al., 1996).

In East-Africa, potato is an important staple crop, with doubled production area over the last 20 years. Mainly CIP varieties and some European varieties are grown. The vast majority of potato is cultivated by millions of small scale farmers, who use farm saved seeds or acquire seed tubers from local markets (Gildemacher et al., 2009). The average yield in East African countries is low and ranges between 5 and 15 ton/ha (Gildemacher et al., 2009; Janssens et al., 2013; FAOstat, 2016). The propagation, storage and distribution of high quality seed tubers is the main constraint that limits production. Therefore, there is a great need for high quality seed tubers or true seeds.

There are several techniques to generate high quality mini-tubers from clean *in-vitro* grown potato plantlets (Tierno et al., 2014). This requires a formal potato production chain as these technologies are applied in specialised companies or public institutes and several rounds of clonal propagation are used before the seed tubers are distributed to the farmers. During these rounds of clonal propagation, the seed tubers may become contaminated with pathogenic micro-organisms. This is even more harmful when farmers keep tubers for next season as the costs of formal seed tubers may be too high for refreshment at each cultivation cycle (Kaguongo et al., 2008). This will further deteriorate the quality of the seed tubers (Thomas-Sharma et al., 2016).

Recently, Solynta has developed a true hybrid breeding system in diploid potato, whereby homozygous parent lines are developed by several rounds of inbreeding and hybrid cultivars are generated by crossing these parent lines (Lindhout et al., 2011). This method enables the creation of true seeds that are genotypically uniform. The starting material was an interspecific cross between diploid potato and the wild species *S. chacoense*, that was used to overcome the self-incompatibility (Lindhout et al., 2011). It took many rounds of crossing, selfings and selections to increase the performance of the inbred lines and to generate the first experimental hybrids (Lindhout et al., 2017). This paper describes the first trials with these experimental hybrids in tropical highlands, in Congo DR. The comparison of hybrid performance in Congo and The Netherlands is made. The results show the potential of hybrid potato for East-Africa.

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2 Materials and methods

2.1 Genetic material

Inbred lines of diploid potato were developed in a dedicated diploid breeding programme as described by Lindhout et al. (2011; 2017). In winter 2014/15 the first series of 203 hybrid crosses were made. Typically, the parents of these hybrids were obtained after several rounds of crossing and selfings followed by at least three rounds of selfing. As an example, the pedigree of hybrid SOL1-7 is shown in Figure 1. From this figure, it becomes clear that the three heterozygous diploid founders (D1, D2 and D16) were crossed with the *Sli*-donor DS, to create self-compatible populations (Lindhout et al., 2011). Subsequent generations of selfing resulted in homozygous parents of the hybrid SOLH1-7. Ten hybrids were selected as representatives for this series of 203 hybrids for further testing in DRC and designated SOLH1 - SOLH-10.

2.2 Selection of potato hybrids in The Netherlands

In 2015, the very first series of 203 experimental diploid potato hybrids were grown in The Netherlands to produce seed tubers. On May 1st, 2015, 100-200 seeds of these hybrids were sown in seed-boxes substrate in a heated greenhouse with 16 hours' day length. The seedlings were transplanted in Est, The Netherlands on June 2nd 2015, in irrigated ridges at 30 cm spacing within a ridge and 75 cm distance between the ridges in one replicate with plant numbers dependent on the number of seedlings available. Soil type was a heavy fluvial clay soil (28% clay). A typical crop management scheme was applied: fertilization and crop protection was done as recommended. Aphids were controlled by weekly chemical treatments combined with mineral oil. The first two weeks after transplanting overhead irrigation was applied two times to protect the seedling against drying out. Tubers were harvested on September 25th, two weeks after chemical defoliation of the plants by Reglone® (diquat dibromide). The tuber weight was evaluated per plot.

2.3 Field trial with potato hybrids in DRC

The experimental site was located at Nioka, Albertine Rift in Ituri Province, Democratic Republic of Congo at 1680 m.a.s.l. The site was chosen for its representativeness for the potato growing environment in the highlands of East-Africa. On January 25th, 2016, 200 seeds of the ten selected experimental hybrids, designated SOLH1-SOLH-10, were sown in seed-boxes with a substrate composed of goat manure, straw, ash and sand. The seed-boxes were placed

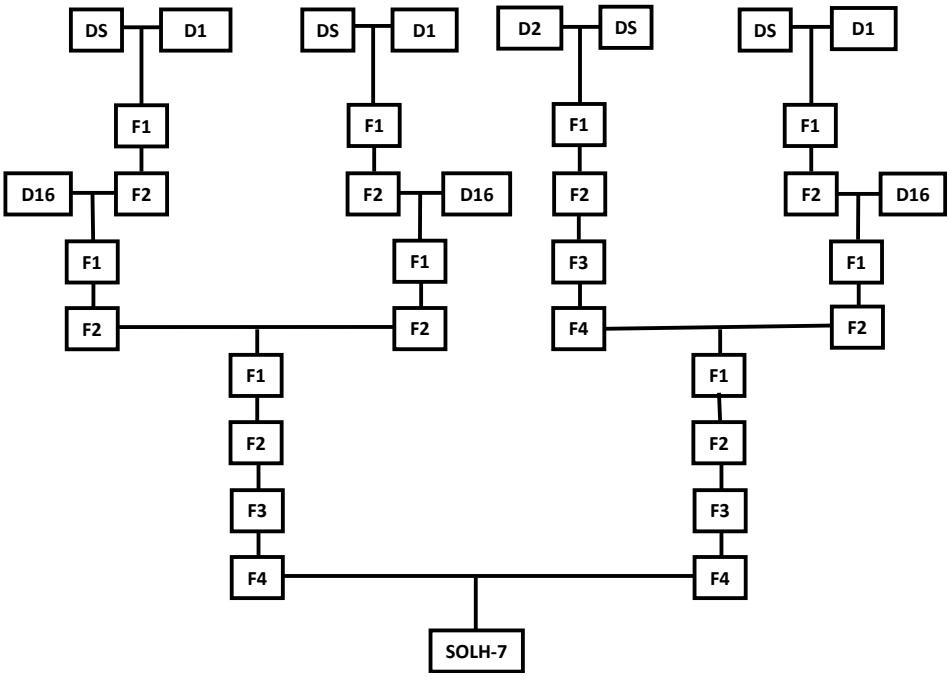

Fig 1. A typical example of an experimental diploid potato hybrid "SOLH-7", obtained by various crossing among the diploid founders D1, D2 and D16 and the Sli-donor DS (see Lindhout et al., 2011)

in an open shed, with a roof to protect against the sun and nets to protect against insects. The seedlings were transplanted on March 10th, in irrigated ridges, with 30 cm spacing within a ridge and 75 cm spacing between the ridges. The experiment was planted in three non-random replicates of 18 to 39 plants per plot, depending on the number of plants available. During the first two months after transplanting hand watering was done to protect the seedlings against drying out. Tubers were harvested on July 1st, when all plants had naturally died. The tuber weight and tuber number per plant was evaluated per plot.

3 Results

The seedlings of the first series of 203 experimental diploid potato hybrids were grown in the field in the Netherlands and evaluated for yield. The germination rate was 74 to 99%. After emergence, 6-weeks old seedlings were transplanted in the field. The growth of the field-plants was artificially stopped after 116 growing days. The tuber yield per plant varied from 0 to 580 gr, which is equivalent to 0 to 26 ton/ha (not shown). A representative set of ten hybrids was selected for trialing in DRC and designated SOLH-1 to SOLH-10.

In many regions in Africa, the potato yield, starting from seed tubers, is only 5 to 10 tons/ha. The greatest constraint is the quality of the seed tubers. True potato seeds are completely free of contaminating pathogens and may solve the lack of good potato starting materials. Therefore, a field trial starting with true seeds of the ten selected experimental hybrids was done in Nioka, Congo DR.

The germination rate after two weeks was on average 64%, ranging from 54 to 76%. After transplanting, a total of 1320 seedlings developed into plantlets, that were between 5-8 cm tall and had on average 8 true leaves at transplanting.

All available seedlings were transplanted into ridges according the standard cultivation techniques, resulting in plot sizes of 110 to 140 plants. Irrigation was performed during the first two months after transplanting but not during the last two months. Visual observation of damage was noted and 54 cases of insect damage during the growing season were noted, assessed as different types of crickets and ants. As there was no rain from 90 days after transplanting all plants were dead at the beginning of the harvest at 113 days after transplanting into the field.

The tuber yield ranged between 167 (SOLH-8) to 640 grams (SOLH-7) per plant, which is equivalent to 8 to 29 ton/ha (Fig 2). Tuber number ranged from 11 (SOLH-5) to 37 (SOLH-7) per plant, with 17 to 48 gr/tuber (not shown). SOLH-1 had the highest number of tubers in the 40-60mm class: three per plant.

The yield data of the same genetic materials at two locations allow to study the genotype x environment (GxE) interaction. Therefore, we compared the yield in gr/plant between the field trial in Democratic Republic of Congo and in The Netherlands (Fig 3.). Despite the large

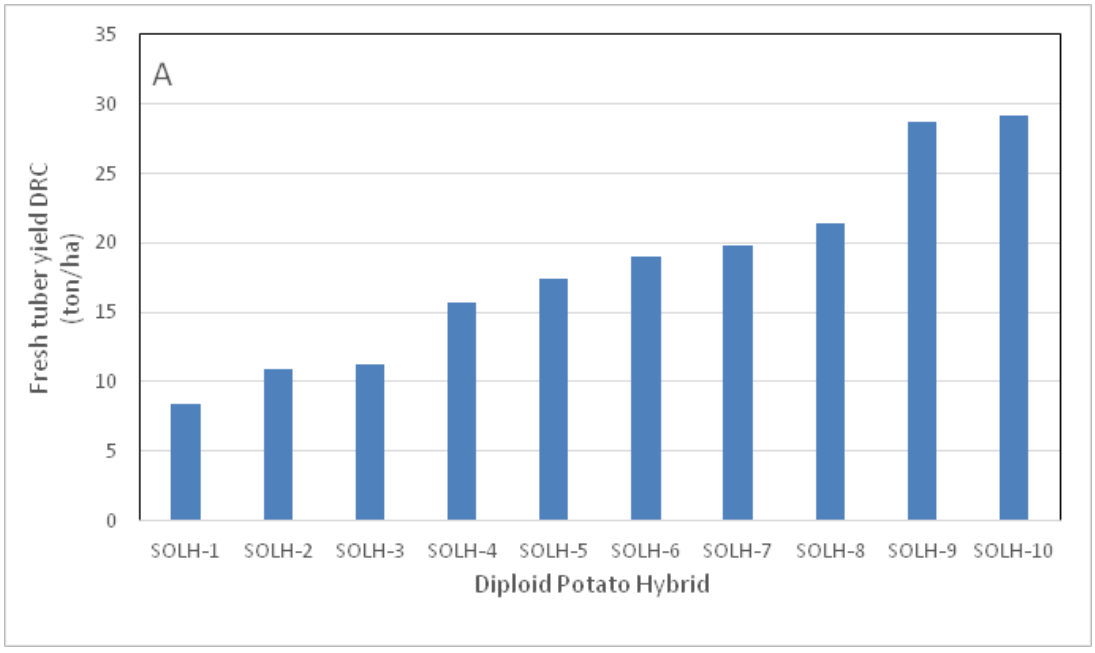

Fig 2. Yield data of ten experimental diploid potato hybrids, grown from seedlings in a field trial in Nioka, DR Congo

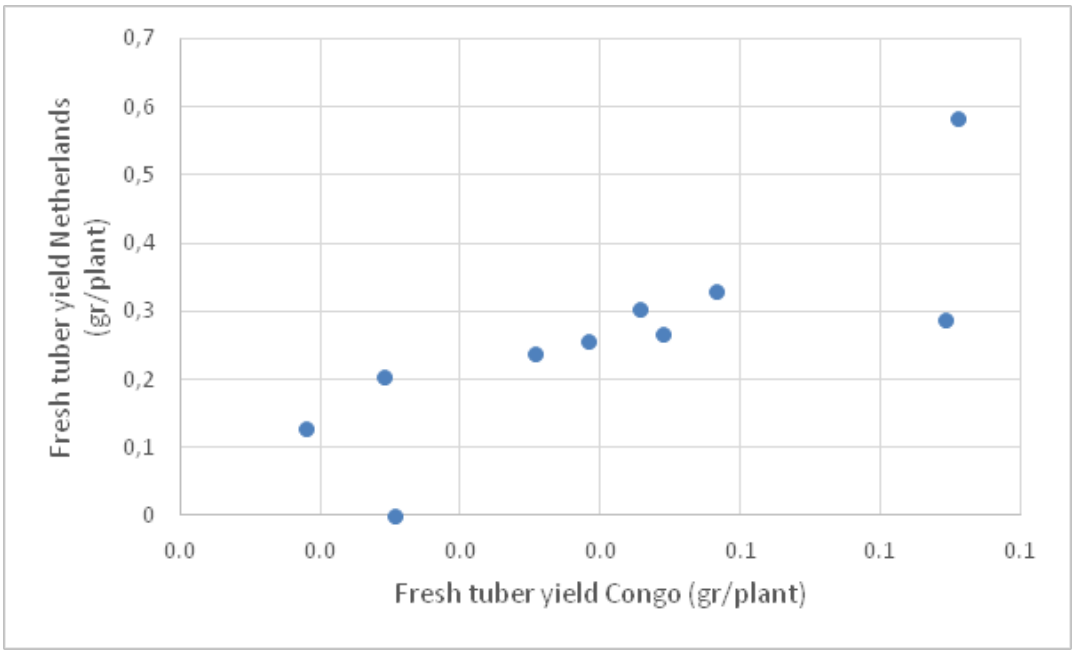

Fig 3. Correlation between the yield in gram/plant of ten diploid experimental potato hybrids in Congo DR compared to The Netherlands

difference in climatic conditions, geographical location and agricultural practices at both locations, we observed a striking correlation between both field tests, whereby the top five hybrids and the bottom five hybrids in both locations were identical.

4 Discussion

This paper describes the very first trial with the very first experimental diploid potato hybrids, generated from advanced inbred lines, reported ever. Before 2014, no dedicated crosses were made to generate experimental hybrids. One of the advantages of hybrid seeds as the number of seeds produced in the first cross as usually 50 to 250 seeds are collected and this number is sufficient to test the performance at multi-locations. In the present study two very distant locations in the world were chosen as the first testing sites for hybrids grown from seeds.

The parents of the hybrids were only selfed for three generations after the last breeding cross (Fig. 1). So, these parents may contain 10 to 20% heterozygous loci. Giving the very large genetic variation in potato (PGSC, 2011; Uitdewilligen et al., 2013; Visser et al., 2014), these parents may show phenotypic segregation for many traits. The main aim of the present study is to evaluate the yield of experimental hybrids and therefore we paid little attention to other traits that were expected to segregate.

The average yield in East Africa ranges from 5 ton/ ha in Uganda to 14 ton/ha in Kenya (FAOstat, 2016). The diploid potato hybrids yielded 8 to 29 ton/ ha in DRC, even higher than in The Netherlands with max. yield of 26 ton/ha. This higher yield in DRC is most likely due to the more favourable weather conditions at the tropical highlands, where the temperature is ideal for potato cultivation, while the harsh spring in The Netherlands is often too cold for potato plant growth.

Compared to the average yield in East Africa of 7 to 15 ton/ ha, the yield of the highest yielding potato hybrids was 29 ton/ha. This extra yield may also be due to optimisation of the cultivation conditions with such as fertilization and irrigation. The tuber number was high, up to 37, while the tuber size was small (17-48 gr/tuber), compared to 50-100 gr for usual tuber weight range (Struik & Wiersema, 2012). Extension of the growing period by irrigation could be a way to increase yield. Further research with tubers raised hybrid plants and tuber raised controls is needed to better dissect the cultivation conditions with the genetics, combined with the effect of clean seeds.

The yield of the highest yielding diploid hybrid in The Netherlands was about half of the yield of seed tuber production of 35 - 40 ton/ha (FAOstat, 2016). So, the highest yielding hybrid, grown from seedlings, showed about half the yield of a commercial tetraploid hybrid, grown from seed tubers.

It is known that seed tubers (raised from tubers) give higher yields than seedling transplants (raised from seeds) (Almekinders et al., 1996; Muthoni et al., 2014). In addition, diploids show lower yields than tetraploids

(Hutten et al., 1994), though interspecific diploid progenies may show high yields as well (Jansky et al., 2016). In this study, we introduce the first diploid potato hybrid. The genetic origin of this breeding system is an interspecific cross between *S. tuberosum* and *S. chacoense* (Lindhout et al., 2011; Fig 1.). The plants of the early selfed progenies were extremely weak (Lindhout et al., 2017) and we did not expect that the very first experimental diploid potato hybrid already have high yields. However, a yield of 50% of the best hybrid grown from seeds compared to the yield of tetraploid seed tuber starting from seed tubers is remarkably high.

The 50% lower yield is due to three confounded factors: diploid versus tetraploid, experimental hybrid versus commercial cultivar and seedlings versus seed tubers. Further tests with tuber grown plants and tetraploid experimental hybrids are needed to dissect these factors.

These results illustrate the potential of diploid hybrid potato in combination of good cultivation practises. In the present study, the cultivation period in DR Congo was restricted by the lack of rainfall. We expect that with a better irrigation system or during the rainy season the yield of these hybrids would have been even higher. In addition, these were the very first hybrids generated by crossing parents without any a prior information about general combining abilities (GCA) of the parent lines. The present results are being used to select parent lines based on high GCA values. New parent lines will also be more inbred and hence more homozygous and more uniform. As a result, the next series of hybrids, is expected to be more advanced, both in terms of tuber yield, tuber quality as well as tuber uniformity.

In addition, by using marker assisted backcrossing programmes a new series of hybrids with new traits can be obtained such as disease resistances to *Phytophthora infestans* and tuber quality (Lindhout et al, 2017). Finally, locally popular tetraploid varieties such as Kinigi in Rwanda could be exploited for a dedicated diploid hybrid potato programme for East Africa to develop a hybrid, that is optimally adapted to the climate conditions and market preferences in East Africa. However, such an effort is to start a breeding programme anew, therefore it may take ten years to have the first hybrid released to the market.

In conclusion, hybrid potato has shown a great potential and will pave the way to a prosperous potato food chain that will contribute to feed the present and future fast growing populations in East Africa.

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