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# Characterization and Evaluation of Potato Genotypes (*Solanum tuberosum L*) for Tolerance to Drought in Uganda

**V. E. Kesiime[1] · G. Tusiime[2] · I. N. Kashaija[3] · R. Edema[2] · P. Gibson[2] · P. Namugga[3] · R. Kakuhenzire[4]**



**Abstract** Potato production in Uganda is being affected by rainfall fluctuations in both timing and amount, resulting into inadequate soil moisture availability and low productivity. Also, potato production is expanding into locations at lower altitudes, where drought is more common. Therefore, drought stress mitigation measures and coping mechanisms need to be devised to face future challenges of climate change, particularly in developing countries to ensure steady supply of adequate quantities of quality food. This study thus, aimed at characterizing new potato clones from CIP (International Potato Center) for tolerance to drought under Ugandan conditions. Consequently a screen house experiment was conducted twice at Kachwekano Zonal Agricultural Research and Development Institute (KAZARDI) from October 2011 to February 2012 and April to July 2012 to evaluate and characterize eight potato genotypes; five of which were obtained from CIP's breeding collection for drought tolerance and low altitude areas, and three locally released varieties from Uganda. These clones were tested for drought tolerance at three levels of simulated moisture deficit; 25 % field capacity, 50 % and 100 % field capacity (FC). Data were collected on leaf chlorophyll content, relative leaf water content, number of days to 50 % flowering, percent ground cover, leaf area, plant height, number of stems per plant, stem diameter, stress score, increment in plant height after imposing stress, tuber dry matter content and yield components. Of all the traits evaluated, yield and number of days to 50 % flowering contributed most to drought tolerance among the potato genotypes evaluated. There were significant ($P \leq 0.05$) differences among genotypes for all evaluated traits. Results from both growth, physiological and yield parameters revealed that the new potato clones were less affected by drought stress compared to adapted varieties. Total tuber yield was 23 tons per hectare, 11.4 and 8.1 in plots at full field capacity, 50 % and 25 % moisture stressed plots respectively in the first experiment. A similar trend was obtained in the second experiment with 19 tons per hectare, 13.7 and 11.3 respectively. The new clones at highest moisture stress had significantly ($P \leq 0.05$) higher yields than adapted varieties providing a promise for possible new varieties and breeding stock in extreme conditions of moisture deficit.

**Resumen** La producción de papa en Uganda esta siendo afectada por fluctuaciones de lluvia, tanto en tiempo como en cantidad, lo cual resulta en una disponibilidad inadecuada de humedad en el suelo y baja productividad. También, se esta expandiendo la producción de papa en localidades a bajas altitudes, donde la sequía es más común. De aquí que las medidas de mitigación del agobio hídrico y los mecanismos para hacerle frente necesitan idearse para encarar futuros retos de cambio climático, particularmente en países en desarrollo, para asegurar un suministro constante de cantidades adecuadas de alimento de calidad. Este estudio, en consecuencia, esta dirigido a la caracterización de clones nuevos de papa del CIP (Centro Internacional de la Papa) para tolerancia a sequía bajo las condiciones de Uganda. Consecuentemente, se condujo un experimento de invernadero por duplicado en el

✉ V. E. Kesiime
eunicekesiime@gmail.com

[1] National Crops Resources Research, Institute Namulonge, 9km Gayaza-Zirobwe road, P.O. Box 7084, Kampala, Uganda

[2] Department of Agricultural Production, Makerere University, P. O. Box 7062, Kampala, Uganda

[3] Kachwekano Zonal Agricultural Research and Development Institute, P. O. Box 421, Kabale, Uganda

[4] International Potato Centre (Tanzania), P. O. Box 2473, Morogoro, Tanzania

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Instituto Regional Kachwekano de Investigación y Desarrollo Agrícola (KAZARDI), de octubre de 2011 a febrero de 2012, y de abril a julio del 2012, para evaluar y caracterizar ocho genotipos de papa; cinco de los cuales se obtuvieron de la colección del mejoramiento del CIP para tolerancia a la sequía y a áreas de baja altitud, y tres variedades liberadas localmente de Uganda. Estos clones se probaron para tolerancia a la sequía a tres niveles de déficit de humedad simulado; 25 % de capacidad de campo, 50 % y 100 % de capacidad de campo (FC). Se obtuvieron datos del contenido de clorofila de la hoja, el contenido relativo del agua en la hoja, número de días para el 50 % de floración, porcentaje de cubierta del suelo, área foliar, altura de planta, número de tallos por planta, diámetro del tallo, nivel de agobio, incremento en la altura de la planta después de la exposición al estrés, contenido de materia seca del tubérculo, y componentes del rendimiento. De todas las variables evaluadas, el rendimiento y el número de días al 50 % de la floración, fueron los que más contribuyeron a la tolerancia a la sequía entre los genotipos de papa evaluados. Hubo diferencias significativas ($P \leq 0.05$) entre los genotipos para todas las variables evaluadas. Los resultados tanto de crecimiento como de los parámetros fisiológicos y de rendimiento revelaron que los clones nuevos de papa fueron menos afectados por el agobio hídrico comparados con las variedades adaptadas. El rendimiento total del tubérculo fue de 23 ton/ha, 11.4 y8.1 en lotes a capacidad de campo total, 50 % y 25 % de agobio de humedad, respectivamente, en el primer experimento. En el segundo experimento se obtuvo una tendencia similar con 19 ton/ha, 13.7 y 11.3, respectivamente. Los nuevos clones expuestos al más alto agobio de humedad tuvieron más alto rendimiento significativamente ($P \leq 0.05$) que las variedades adaptadas, proporcionando una promesa para posibles nuevas variedades y material de mejoramiento en condiciones extremas de déficit de humedad.

**Keywords** Simulated drought stress · Watering regime and moisture deficit

## Introduction

Rainfall intensity and reliability in south western Uganda as in many other tropical highlands, has become very unpredictable with huge seasonal and annual fluctuations every other year. The quantity of rainfall received per year has retrogressively decreased since 1961. At the same time temperature changes have been more pronounced at higher altitudes than in the lowlands where higher optma than before continue to be experienced. The temperature in Kabale district for example has increased by 2 °C (3.6 °F) since 1980 (Wandiga 2004).

Also in Uganda the area of substantial potato production expansion potential happens to be in lower altitudes where drought is more common while potato production is increasing in popularity. The current global warming, which causes fluctuations in precipitation distribution, increases the risk of plants being exposed repeatedly to drought with possible negative impacts on crop yield and quality (Miyashita et al. 2005), and potato yield losses are likely to increase. Potato among other crops is likely to be affected most considering that it is a cool temperature- requiring crop that performs well in ample supply of soil moisture.

Potato (*Solanum tuberosum L*) is both a staple food and major source of household income in the highlands of Uganda and most countries in Africa. Uganda has consistently been among the 12 African potato producers in acreage and tonnage but not productivity (Table 1). Despite the importance of potato in Uganda, local farm yields have remained below 10 tons $ha^{-1}$compared to the African average and what can be potentially obtained (25 t $ha^{-1}$) under optimal growth

**Table 1** 12 top potato production countries in Africa

| | Country | Areas where potato is grown in top 12 African producing countries | Tones | Yield (t/ha) | Area under production |
|---|---|---|---|---|---|
| 1 | Algeria | Mediterranean coast, atlas mountains and high plateau areas (500masl) | 4,928,028 | 30.3 | 162,707 |
| 2 | Egypt | Nile river delta | 4,800,000 | 27.0 | 178,000 |
| 3 | Malawi | Highland areas in the south and central regions(1000–2000masl0 | 4,535,955 | 17.5 | 258,586 |
| 4 | South Africa | | 2,252,000 | 34.1 | 66,000 |
| 5 | Rwanda | Several parts | 2,240,715 | 13.6 | 164,691 |
| 6 | Kenya | Highland areas (1200–30000masl | 2,192,885 | 14.4 | 152,007 |
| 7 | Morocco | Along the atlantic coast, north and south of casablana, atlas mountains at elevations more than 3000masl | 1,928,606 | 36.4 | 53,047 |
| 8 | Tanzania | | 1,767,536 | 8.7 | 203,165 |
| 9 | Nigeria | Jos plateau (1200–1400 m) | 1,200,000 | 4.5 | 263,997 |
| 10 | Ethiopia | Highland areas (1500masl) | 775,503 | 11.1 | 69,999 |
| 11 | Uganda | Highland areas (2000masl) | 774,600 | 7.3 | 106,001 |
| 12 | Angola | Highland areas of Huambo province | 670,136 | 6.3 | 105,862 |

conditions (PRAPACE 1996; IITA-FOODNET et al. 2001). Some of the causes of low productivity include but are not limited to diseases such as late blight, bacterial wilt, potato viruses, inappropriate agronomic practices, low quality seed and lack of suitable varieties. Recently unexpected variability in climatic pattern resulting into drought presents the major and emerging threat to potato production in Uganda. This is aggravated by dependence on rainfall for agriculture due to low availability of irrigation technologies in Uganda and unaffordable associated costs for small holder farmers.

In most crops including potato, drought is responsible for reduced number of leaves, reduced leaf area, plant dwarfing, limited ground coverage and yield reduction in susceptible crop cultivars (Hassanpanah 2010). Prolonged soil moisture deficit produces small or cucumber shaped tubers while intermittent water availability produces knobby tubers or tubers with secondary growth in susceptible varieties (Nolte et al. 2003) besides reduction in yield. Therefore, there is need to identify genotypes that are able to with stand drought stress with little impact on total fresh tuber yield and quality. This study thus aimed to identify breeding materials that are tolerant to drought and have potential to provide acceptable yield and quality under moisture stressed conditions.

## Materials and methods

A screenhouse experiment was conducted at Kachwekano Zonal Agricultural Research and Development Institute (KAZARDI), Kabale district in south western Uganda to characterize potato genotypes for tolerance to drought. Kachwekano ZARDI is situated at 0290 57′E 010 16′S at 2200 m above sea level. The area receives a bimodal rainfall regime with March-May as the first rainy season and September –December as the second season that would influence open field crop production. The experiment was repeated twice, once in the second rainy season of 2011 and again in the first rainy season of 2012. Eight potato genotypes were used; five clones were obtained from CIP's breeding collection for drought tolerance and adaptation to low altitude areas while the other three were popular varieties already released in Uganda with unknown tolerance to drought (Table. 2).

## Experimental Procedure and Design

The clones were tested for drought tolerance at three levels of simulated moisture deficit in a split plot design. The moisture deficit treatments were taken as full field capacity, 50 % field capacity and 25 % field capacity. A split plot design was adopted where moisture deficit levels constituted the main plots while the potato genotypes comprised of the sub plots. Wooden boxes, 3.0 m long and 1.1 m wide were used for the main plot treatments. The boxes were sub-divided into eight partitions each 0.75 m long by 0.55 m wide and each partition accommodated one potato genotype. For each sub-plot, four fully sprouted and physiologically mature seed tubers were planted. Each simulated moisture deficit regime by potato genotype treatment combinations were replicated four times, thus twelve boxes were used ((Fig. 1).

**Table 2** Clones and Varieties that were used in the study

| Genotype | Origin | Response to drought |
|---|---|---|
| Uganda 11 | KAZARDI | Unknown |
| Victoria | KAZARDI | Unknown |
| Kachpot1 | KAZARDI | Unknown |
| 394034.7 | CIP | Tolerant |
| 395017.242 | CIP | Tolerant |
| 393315.1 | CIP | Tolerant |
| 391591.96 | CIP | Tolerant |
| 393077.159 | CIP | Tolerant |

*CIP* International Potato Center, *KAZARDI* Kachwekano Zonal Agricultural Research and Development Institute

In each box, the partitions were individually lined by a G1000 polythen sheet, before adding soil, to prevent wood-water contact that would cause fungal growth and box timber from rotting. In each partition 67 kg of steam sterilized soil were added to a depth of 18 cm. Fertilizer (NPK 17:17:17) was applied at a rate of 100 kg $ha^{-1}$ uniformly across the experimental plots by mixing it thoroughly in the top 10 cm of the soil. In each partition representing a genotype, four seed tubers at the same sprouting level were planted.

## Application of Moisture Deficit Treatments

All the plots after planting were watered to full field capacity for the first eight weeks which coincided with tuber initiation. This is because tuber initiation is a critical stage in potato development which requires adequate moisture. Thereafter, the experimental plots were subjected to one of the three watering regimes simulating different levels of moisture deficit, where one set was watered optimally (four liters), another given half the optimum amount (two liters) and the third set a quarter (one liter).

The Field capacity of soil was determined by picking 3 soil samples from different positions and levels using a soil augar, after saturating one cubic meter of soil outside the screenhouse and leaving it to drain freely overnight. The samples were then bulked and their initial weight taken. The bulked samples were then oven dried at 105 °C to constant mass and the amount of water at field capacity calculated as the difference between the initial weight of soil and the weight of soil at constant mass. The volume of water per kilogram of soil

was computed and used to determine the full field capacity for 67 kg of soil in each box partition. This amount of water was approximately four liters of water for full field capacity, thus determining half and quarter field capacity as two and one liter of water per box partition with four potato plants. Watering was done manually by uniformly spreading the measured amount of water over the soil in each plot by hand once every week.

## Data Collection

Leaf area was calculated after measuring the entire leaf width and length using a meter rule from the leaf stalk to the leaf tip of the 7$^{th}$ leaf of two adjacent plants. This was because the 7$^{th}$ leaf was the most open and thus easy to measure. It was tagged for identification as growth continued. Soil moisture content was measured daily using a ZD-06 Handheld Metal Electrode Moisture Probe with a 1–8 analog scale based on electrical conductivity (Sunflower supplies, LLC 3104 Expressway Dr South Islandia, NY 11749) and oven drying at weekly interval. Amount of water in the soil in each partition was obtained by sampling soil from three soil depths; top (5 cm), middle (15 cm) and bottom (25 cm) using a soil auger. The samples were then bulked together in crucibles of known weight, weighed and oven dried at 105 °C for 48 h to constant mass. The amount of water in the soil was then calculated from the difference between weight of the crucible with soil before and after oven drying.

The chlorophyll content of experimental potato plant leaves was measured using the Opti-plex chlorophyll meter CCM-200, with units of "relative vegetative index" based on absorbance at 650 nm compared to 940 nm (CCM-200-Opti-sciences, Inc, Hudson, New Hampshire). Measurements were taken from two leaves per plant per sub-plot and an average obtained. Plant height was measured using a meter rule from the soil level in the box to the tip of the tallest potato plant branch. The water used by the plants in each box partition was calculated based on the amount of irrigation water added and soil moisture measurements. Percentage ground cover was visually estimated on a 0–100 % scale where 100 % refers to plots where soil couldn't be seen from the top of the box. The number of stems on each plant per sub-plot was counted and recorded. Moisture stress was scored following the CIP scale (Mohammad 2007 where;

1 = plots where all the plants and leaves were green and turgid
2 = plots where only 30 % of the plants or leaves had wilted
3 = 50 % of the plants or leaves wilted
7 = 80 % of the plants or leaves wilted
9 = 100 % of the plants and leaves wilted or complete death of the plant.

The relative leaf water content (RLWC) as a percentage between leaves at full turgour and oven dried leaf tissue was determined by sampling three leaves from one plant (upper, middle and lower level per plant in the same location from each plot). Three square centimeter leaf discs were cut from each leaflet and immediately placed in Petri dishes containing distilled water and stored at 4 °C overnight. The leaf discs were then removed from Petri dishes blotted to surface-dryness with tissue paper and weighed to determine the weight of the leaf discs at full turgor. The discs were then dried in an oven overnight at 90 °C for 12 h and then re- weighed immediately after cooling to determine the leaf disc dry weight. The relative water content (RLWC) of the leaves was determined from Eq. 1 (Boyer et al. 2008).

$$RLWC\% = FW-DW/TW-DW)*100 \quad (1)$$

Where;

FW is the fresh weight of discs after collection
DW is the dry weight of discs after oven drying
TW is the weight of discs at full turgour.

After full maturity of plants under field capacity treatment, the experimental crop was harvested and the number and weight of tubers per sub-plot was determined. Two, 30–40 mm diameter tubers from each treatment combination were


**Fig. 1** Showing the experimental layout

collected and used to determine tuber dry matter content. The sample tubers were sliced into small pieces to increase the surface area for faster drying. The fresh tuber slices were weighed, dried in an oven at 80° C for 48 h and re-weighed to determine dry weight. The dry matter content was expressed as a percentage of dry weight over fresh weight (g) (Ekanayake 1990; Jones 1993).

## Data Analysis

The significance of treatments for quantitative data were tested using analysis of variance in Genstat 14th Edition. Means of significant treatment main effects and interactions were compared using Fisher's protected least differences (LSD) at 5 % probability. The skeleton anova for the analysis is shown in Table 3.

## Results and Discussion

### Response of Potato Genotype to Moisture Deficit

Analysis of variance for effect of watering regime and potato genotype on the measured variables as indicators of drought tolerance indicated that there were significant differences among potato genotypes for all traits evaluated, apart from chlorophyll content in both experiments and Relative leaf water content in the first experiment (Tables 4 and 5). These were number of days to 50 % flowering, percent ground cover, leaf area, plant height, number of stems per plant, stem diameter, stress score, increment in plant height after imposing stress and dry matter content.

In the first experiment, significant differences across the three watering regimes were obtained for percent groundcover, stress score, dry matter content, increment in plant height and

**Table 3** Skelton anova for the analysis

| Source of variation | DF | Type of effect | Expected mean squares | F-test denominator |
|---|---|---|---|---|
| Total | 95 | | | |
| Replications | 3 | Random | $\sigma^2$e +24 $\sigma^2$reps | Main plot error |
| Watering regimes | 2 | Fixed | $\sigma^2$e +32 $\sigma^2$W | Main plot error |
| Main plot error | 6 | | $\sigma^2$e (main plot error) | Sub-plot error |
| Genotypes | 7 | Fixed | $\sigma^2$e +12 $\sigma^2$G | Sub-plot error |
| Watering regime X genotype | 14 | Fixed | $\sigma^2$e +4 $\sigma^2$ W x G | Sub-plot error |
| Sub-plot error | 63 | | $\sigma^2$e (sub-plot error) | |

**Table 4** ANOVA of tested indicators of drought stress in the first trial of characterizing potato genotypes for tolerance to drought. (2011B)

| Source of variation | d.f | Leaf Area (cm) | No. of stems | Plant height (cm) | Ground cover (%) | Stem diameter (mm) | Increment in plant height (cm) | Stress score | Dry matter content | Days to 50 % flowering | Chlorophyll content | Relative leaf water content |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Replication | 3 | 17823 | 1.84 | 518.6 | 117.1 | 0.04 | 96.21 | 1.86 | 36.9 | 4.49 | 16.26 | 2.8 |
| W-R | 2 | 33095$^{*}$ | 2.91 | 1120.4 | 665 .50$^{***}$ | 0.15$^{*}$ | 413.3 | 172.2$^{***}$ | 21.6$^{*}$ | 7.41 | 78.35 | 589.6 |
| MP Error | 6 | 5845 | 7.91 | 1080.2 | 132.6 | 0.02 | 278.03 | 5.99 | 2.8 | 39.85 | 37.42 | 40.2 |
| G | 7 | 304904$^{***}$ | 13.17$^{**}$ | 2525.2$^{***}$ | 222.5$^{***}$ | 0.93$^{***}$ | 271.3$^{*}$ | 16.1$^{***}$ | 43.6$^{***}$ | 195.18$^{***}$ | 70.19$^{*}$ | 115.5 |
| W-R-G | 14 | 19002 | 4.34 | 147.4 | 64.2$^{**}$ | 0.61 | 144.31 | 6.3$^{*}$ | 5.7 | 9.97 | 22.29 | 43.4 |
| SP Error | 63 | 23095 | 3.89 | 205.1 | 20 | 0.06 | 93.64 | 3.07 | 3.7 | 26.63 | 30.03 | 106.2 |

*W-R* watering regime, *MP Error* main plot error, *G* genotype, *W-R-G* watering regime by genotype, *SP Error* sub-plot error

*, **, ***, significant at 0 ≤ 0.05, 0.01 and 0.001 respectively. Those without stars were not significant

**Table 5** ANOVA of tested indicators of drought tolerance in the second trial. (2012A)

| Source of Variation | d.f | Leaf Area (cm) | No. of Stems | Plant Height (cm) | Ground Cover (%) | Stem Diameter (mm) | Increment in Plant Height (cm) | Stress Score | Dry Matter Content | Days to 50 % Flowering | Chlorophyll Content | Relative Leaf Water Content |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Replication | 3 | 7161 | 0.2 | 2197.6 | 195.2 | 0.04 | 88.5 | 3.99 | 24.6 | 24 | 47.28 | 19.23 |
| W-R | 2 | 555 | 0.1 | 405 | 1632.2*** | 0.07 | 3822.7*** | 125.6*** | 205.6* | 729.4 | 14.97 | 1700.08* |
| MP Error | 6 | 46090 | 0.2 | 536.8 | 47.2 | 0.03 | 108.4 | 2.09 | 18.4 | 229.3 | 49.14*** | 75.08 |
| G | 7 | 162725*** | 5.9*** | 5517.4*** | 1483.0*** | 0.68*** | 615.9*** | 20.3*** | 140.0*** | 1394.7*** | 866.2*** | 80.21 |
| W-R-G | 14 | 17426 | 0.6 | 80.7 | 50.9 | 0.02 | 140.2** | 6.9*** | 7.1 | 179.5*** | 24.1* | 19.38 |
| SP Error | 63 | 11443 | 0.4 | 83.1 | 51.5 | 0.02 | 55.9 | 0.6 | 9.3 | 38.3 | 9.8 | 50.4 |

**Table 6** Effect of moisture deficit levels on different parameters evaluated

| WR Genotype | FC PH | 50 %FC | 25 %FC | FC IPH | 50 %FC | 25 %FC | FC GC | 50 %FC | 25 %FC | FC RLWC | 50 %FC | 25 %FC | FC LA | 50 %FC | 25 %FC | FC CLPL | 50 %FC | 25 %FC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 391533.1 | 88 | 82.8 | 87.9 | 21.1 | 13.8 | 11.4 | 54.8 | 54 | 51.6 | 81.61 | 76.5 | 63.95 | 493.5 | 460 | 461.6 | 18.7 | 23.1 | 21.3 |
| 391691.96 | 110.2 | 107.6 | 106.5 | 34.3 | 14.1 | 15.9 | 55.6 | 52.5 | 49.9 | 76.61 | 70.85 | 59.8 | 490.8 | 486.5 | 459.9 | 28.2 | 32.5 | 30.8 |
| 393077.159 | 95.6 | 85 | 76.9 | 15.9 | 7.4 | 5.5 | 70.6 | 60.4 | 53.1 | 78.8 | 77.57 | 64.34 | 511.9 | 444.8 | 441.2 | 20.9 | 21.6 | 24.8 |
| 394034.7 | 58.9 | 51.1 | 54.6 | 16.5 | 11.5 | 1 | 50.8 | 47.4 | 41 | 80.87 | 77.89 | 71.25 | 379.2 | 295.9 | 328.7 | 15.4 | 15.7 | 28.8 |
| 395017.242 | 83.3 | 75.3 | 72.9 | 16.8 | 15.1 | 4.9 | 69.4 | 59.8 | 55.6 | 78.38 | 69.98 | 63.32 | 560.5 | 864 | 762.6 | 16.7 | 19 | 20.2 |
| Kachpot1 | 96.6 | 84.7 | 86.2 | 32.5 | 9.5 | 10.9 | 71.9 | 63.1 | 60 | 77.07 | 71.1 | 62.46 | 621.9 | 631.7 | 579.6 | 28.6 | 26.3 | 28.8 |
| Uganda 11 | 72.1 | 68 | 68.3 | 24.1 | 7.3 | 7.4 | 73.6 | 63.8 | 56.9 | 83.05 | 76.87 | 67.4 | 573.4 | 454.3 | 447.4 | 33 | 32.2 | 27.1 |
| Victoria | 90.4 | 83.2 | 74.4 | 11.6 | 11.6 | 3.8 | 65.1 | 60.1 | 50.5 | 77.18 | 71.24 | 57.95 | 451.1 | 468.7 | 395.4 | 18.5 | 27.9 | 23 |
| **Mean** | **86.9** | **79.7** | **78.5** | **21.6** | **11.3** | **7.6** | **64** | **57.6** | **52.3** | **79.2** | **74** | **63.81** | **510.3** | **513.2** | **484.5** | **22.5** | **24.8** | **25.6** |
| **LSD** | **10.8** | | | **11.6** | | | **8.4** | | | **4.58** | | | 206.3 | | | 10.8 | | |
| **%CV** | **14.7** | | | **64.1** | | | **10.3** | | | **12.4** | | | 24.4 | | | 24 | | |

*WR* watering regime, *FC* field capacity, *PH* plant height, *IPH* increment in plant height, *GC* ground cover, *RLWC* relative leaf water content, *LA* leaf area, *CHLPLC* chlorophyll content

**Table 7** ANOVA of yield and its components evaluated in the First trial 2011B

| Source of variation | d.f. | Yield in tones/ha | Total no. tubers | Av. weight of tubers |
|---|---|---|---|---|
| Replication | 3 | 74.01 ns | 22.57 ns | 335.82 |
| Watering_regime | 2 | 1849.97*** | 1153.78* | 2321.82*** |
| Main- Plot error | 6 | 48.11 | 111.64 | 85.51 |
| Genotype | 7 | 94.45*** | 644.71*** | 872.88*** |
| Watering regime. Genotype | 14 | 14.51 | 194.04** | 160.62* |
| Sub-Plot error | 63 | 12.99 | 67.13 | 68.6 |

relative leaf water content. The interaction between watering regimes and genotype was significant ($P \leq 0.05$) for stress score, increment in plant height after imposing stress, number of days to 50 % flowering and chlorophyll content (Table 4). In the second trial, watering regimes were significant for leaf area, stem diameter, stress score and dry matter content while the interaction between watering regimes and genotypes was significant only for groundcover and stress score (Tables 5 and 6). Data from the two experiments were not combined due to heterogeneous error variances. This was probably due to differences in environmental effects. The second experiment was affected by aphids which did not succumb to chemical spray thus causing senescence to set in earlier and subsequent dehalming of the trial.

## Effect of Moisture Stress on Yield Performance and the Other Traits Evaluated Within the Two Experiments of Testing

In both trials the effect of moisture deficit varied among genotypes, for both growth parameters and yield components. There were significant differences for yield and yield components in both the first and second experiments (Tables 7 and 8). Mean yield performance in tons per hectare reduced with increase in moisture stress among genotypes, in the first experiment, the overall mean yield in tons per hectare reduced from 23 in field capacity watered plots, to 11.4 in half field capacity watered plots and 8.8 in quarter field capacity watered plots. In the second experiment, yield reduced from 19 in field capacity watered plots, to 13.7 in half field capacity watered plots and 11.3 in quarter field capacity watered plots (Table 9). CIP clones 391533.1 and 394034.7 had the least yield reduction in the first experiment while in the second experiment 391533.1, 394034.7 and 393077.159 had the least yield reductions under severe stress.

The mean ground cover was reduced from 64 % in field capacity watered plots, to 57.6 % in half field capacity and 52.3 % in plots watered at quarter field capacity. The highest percentage ground cover reduction under severe stress was recorded in CIP clone 393077.159 (24.8 %), followed by varieties Uganda 11 (22.8) and Victoria (22.5 %). It was lowest in clone 391533.1 (5.7 %), 391691.96 (10.3 %) and variety Kachpot1 (16.5 %). The overall mean plant height was reduced from 86.9 cm under well watered plots, to 79.7 cm in half well watered plots and 78.5 cm in quarter of the well watered plots. The greatest reduction in plant height was in clone 393077.159 (19.5 %) under severe stress, followed by variety Victoria (17.7 %), and clone 395017.242 (12.4 %). There was less reduction in plant height in clone 391533.1 (0.1 %), followed by 391691.96 (3.3 %) and variety Uganda 11 (5.3 %). The reduction in plant height is probably due to poor cell enlargement caused by water stress. Water stress suppresses cell expansion and cell growth due to low turgour pressure resulting into plant dwarfing and reduced ground coverage (Sharma et al. 2011, Kumar et al. 2007, Shao et al. 2009; Schafleitner *et al* 2007). There was 5.1 % leaf area reduction in severe stressed plots. Uganda 11 had the greatest leaf area reduction (23 %) while clone 391691.96 had the least reduction (6.3 %). Reduction in leaf area is attributed to suppression of leaf expansion through reduced photosynthesis (Shakeel et al. 2011). (Table 9)

Leaf chlorophyll content increased with increase in moisture stress (22.5, 24.8 and 25.6 in the plots watered to field capacity, 50 % field capacity and 25 % field capacity respectively.) Arunyanark et al. (2009) reported a similar finding in peanut. Dry matter content also increased with increase in

**Table 8** ANOVA of yield and its components evaluated in the second trial 2012A

| Source of variation | d.f. | Yield in tones/ha | Total. no. tubers | Av. weight of tubers |
|---|---|---|---|---|
| Replication | 3 | 31.821 | 84.76 | 165.9 |
| Watering regime | 2 | 504.88*** | 23.09 | 2007.56** |
| Main -Plot error | 6 | 18.025 | 114.26 | 112.51 |
| Genotype | 7 | 42.86*** | 236.26*** | 424.91*** |
| Watering regime. Genotype | 14 | 13.05* | 53.94 | 108.24* |
| Sub-Plot error | 63 | 6.819 | 38.88 | 53.37 |

**Table 9** Effect of induced moisture stress on potato total fresh yield in tons per hectare

| Watering Regime | Expt 1(2011B) | | | | Expt 2 (2012A) | | | |
|---|---|---|---|---|---|---|---|---|
| | FC | 50 %FC | 25 %FC | % Yield loss under 25 % FC | FC | 50 %FC | 25 %FC | % Yield loss under 25 % FC |
| Genotype | | | | | | | | |
| 391533.1 | 20 | 12.1 | 10.9 | 45.5 | 16 | 10.2 | 11.3 | 29.4 |
| 391691.96 | 18.2 | 9.7 | 6.7 | 63.2 | 22.4 | 13.6 | 11.7 | 47.8 |
| 393077.159 | 26.7 | 13.9 | 9.4 | 64.8 | 19.6 | 16.4 | 12.5 | 36.2 |
| 394034.7 | 26.7 | 13.9 | 13.3 | 50.2 | 14.8 | 12.4 | 12 | 18.9 |
| 395017.242 | 24.9 | 13.9 | 10.9 | 56.2 | 15.4 | 11.3 | 9.4 | 39.0 |
| Kachpot1 | 19.4 | 6.1 | 4.9 | 74.7 | 20.9 | 15 | 12.6 | 39.7 |
| Uganda 11 | 20.6 | 10.3 | 6.1 | 70.4 | 22.9 | 15.8 | 12.1 | 47.2 |
| Victoria | 27.9 | 10.9 | 7.9 | 71.7 | 20.1 | 15.1 | 8.6 | 57.2 |
| **Mean** | 23 | 11.4 | 8.8 | 61.7 | 19 | 13.7 | 11.3 | 40.5 |
| **LSD** | 5.1 | | | | 3.7 | | | |
| **%CV** | 25.1 | | | | 17.8 | | | |

moisture stress; Field capacity (19.7 %), half field capacity (22.3 %) and quarter field capacity (22.8 %) (Kumar et al. (2007) reported similar findings. The highest tuber dry matter content was in adopted varieties Kachpot1 (25.3 %) and Uganda 11 (24.5 %), which were released based on their high yields, resistance to late blight disease and good processing qualities.

Clones that attained 50 % flowering early, 395017.242 (51 days), 394034.7 (53 days) and 391533.1 (57 days) maintained high yields in the stressed plots. Tuber yields from these plots were: 394034.7 (13.3 tons per hectare), followed by 391533.1 and 395017.242 with both 10.9 in experiment 1 and 394034.7 (12 tons per hectare) and 391533.1 (11 tons per hectare) in the second experiment. (Table 8). These clones could be early maturing, suggesting that they formed tubers before the imposition of stress and thus escaped it (Price et al. 2002). Stress score is a visual indicator of drought stress and is used to identify genotypes that are tolerant to drought. In this study, stress scores were least in clone 395017.242 (1, 2.4 and 3.5 in the well watered, 50 % stressed and 25 % stressed plots respectively), followed by variety Kachpot1 (1, 2.3 and 3.9 in the well watered, 50 % stressed and 25 % stressed plots respectively), 391533.1 (1, 2 and 4 in the well watered, 50 % stressed and 25 % stressed plots respectively), and 391691.96 (1, 3 and 4.5 in the well watered, 50 % stressed and 25 % stressed plots respectively). It was highest in variety Victoria with (1, 7 and 8.5) in the well watered, 50 % stressed and 25 % stressed plots respectively.

There was a high positive significant correlation between leaf wilting recorded as stress score and number of stems per plant (0.85) meaning that the higher the number of stems the higher the stress score (Table 10). Variety Victoria and clone

**Table 10** Correlations of tuber yield and other tested drought tolerance trait means averaged from two trials of the characterization experiment

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Yield | 1 | – | | | | | | | | | |
| LA | 2 | −0.17 | – | | | | | | | | |
| SS | 3 | −0.29 | −0.20 | – | | | | | | | |
| SD | 4 | 0.78* | 0.41 | 0.33 | – | | | | | | |
| RLWC | 5 | 0.09 | −0.56 | −0.45 | −0.19 | – | | | | | |
| PH | 6 | 0.35 | 0.27 | 0.31 | −0.12 | −0.56 | – | | | | |
| NS | 7 | −0.12 | −0.13 | 0.86** | 0.32 | −0.53 | 0.59 | – | | | |
| IPH | 8 | 0.37 | 0.27 | −0.25 | −0.34 | −0.06 | 0.72* | −0.05 | – | | |
| DMC | 9 | −0.22 | 0.25 | −0.03 | 0.35 | 0.13 | 0.47 | 0.16 | 0.69 | – | |
| CHLPL | 10 | −0.23 | −0.04 | 0.11 | 0.24 | 0.24 | 0.44 | 0.23 | 0.61 | 0.91** | – |
| 50 %F | 11 | −0.17 | −0.17 | 0.22 | 0.37 | 0.37 | 0.30 | 0.33 | 0.34 | 0.80* | 0.89** |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

*PH* plant height, *IPH* increment in plant height, *RLWC* relative leaf water content, *LA* leaf area, *CHLPLC* chlorophyll content, *SS* stress score, *SD* stem diameter, *NS* Number of stems, *DMC* dry matter content, 50 % flowering

393077.159 which had the highest number of stems (4) in the severe stressed plots had the highest stress score (1, 7 and 8.5) and (1, 3.4 and 6.5) respectively despite the good yield obtained by clone 393977.159 under severe stress. This could be attributed to many stems competing for the available moisture which was not adequate enough to support all the foliage. Namazzi (2011) reported a similar finding in rice. In her study, genotypes with high tiller numbers also had high leaf rolling scores. Variety Kachpot1 and Uganda 11 did not show severe signs of leaf stress but yielded poorly in the stressed plots. This suggests that most of the moisture was used in maintaining the vegetative parts than tuber formation. The two varieties had the highest percentage ground cover (60 % for Kachpot1 and 56.0 % for Uganda 11) in the severely stressed plots. Relative leaf water content is the most appropriate measure of plant water status in terms of the physiological consequence of cellular water deficit (Brans and Weatherley 1962). In this study, the relative leaf water content was least affected under quarter moisture stress in clone, 394034.7, which had the highest percent relative leaf water content (71 %), followed by 393077.159 (64 %) and then 391750.242 (63 %). It was mostly affected in Victoria with 58 %.

## Conclusion and Recommendation

Potato clones 391533.1 and 394034 .7 were characterized as drought tolerant while 393077.159 and 395017.242 were moderately tolerant based on their physiological, growth and yield responses to drought. The other clones and varieties were susceptible, Victoria being the most susceptible. Clones 391533.1 and 394034 .7 showed comparatively high yields and low yield reduction under drought stress. These two could be further evaluated for release in drought prone zones or utilized as a source of genes to improve existing local susceptible cultivars.

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## References

Arunyanark, A., S. Jogloy, C. Akasaeng, N. Vorasoot, T. Kesmala, R.C. Nageswara, G.C. Wright, and A. Patanothai. 2009. Chlorophyl stability is an indicator of drought tolerance in peanut. *Journal of Agronomy and Crop Science* 194: 113–125.

Brans, H.D., and P.E. Weatherley. 1962. A re-examination of the relative turgidity technique for estimating water deficits in leaves. *Australian Journal of Biological Sciences* 15: 413–458.

Boyer, J.S., R.A. James, R. Munns, A.G. Condon, and J.B. Passioura. 2008. Osmotic adjustment may lead to anomalously low estimates of relative water content in wheat and barley. *Functional Plant Biology* 35: 1172–1182.

Ekanayake, I. J., 1990. Evaluation of potato and sweet potato genotypes for drought resistance. CIP Research Guide 19. International potato centre, Lima, Peru.9–12.

Hassanpanah, D., 2010. Evaluation of potato advanced cultivars against water deficit stress under *in vitro* and *in vivo* conditions. *Biotechnology* : 164–9.

IITA-FOODNET, CIP, PRAPACE, CGIAR and ASARECA, 2001.Uganda's Irish Potato Sector

Jones, H. J, 1993. Drought tolerance and water-use efficiency. In Water deficits, plant response from cell to community. Oxford, UK: BIOS Scientific Publishers, pp. 193–203.

Kumar, R., G.S. Kang, and S.K. Pandey. 2007. Inheritance of resistance to late blight (*Phytophthora infestans*) in potato. *Euphytica* 155: 183–191.

Miyashita, K., S. Tanakamaru, M.T. Maitani, and M.K. Kimura. 2005. Recovery responses of photosynthesis, transpiration and stomatal conductance in kidney bean following drought stress. *Environmental and Experimental Botany* 53: 205–214.

Namazzi, B. S., 2011. Analysis of drought tolerance in selected upland rice genotypes in Uganda. M.Sc. Thesis Makerere University, Uganda, pp 53–57.

Sharma, N., P. Kumar, M.S. Kadian, S.K. Pandey, S.V. Singh, and S.K. Luthra. 2011. Performance of potato (*Solanumtuberosum*L) clones under stress, CIP south west and central Asia Region, New Delhi 110012. *Indian Journal of Agricultural Sciences* 81(9): 825–829.

Nolte, P., J.S. Miller, B.D. Geary, and D.L. Corsini. 2003. "Disease management", chapter 10. In *Potato production systems*, ed. J.C. Stark and S.L. Love. Moscow: Agricultural Communications, University of Idaho. 426 pp.

PRAPACE, 1996. Evaluation of potato germplasm for field resistance to late blight in Eastern and Central Africa. Recommendations and Summaries from regional workshop presentations at Mukono, Uganda 21Pp.

Price, A., J. Cairns, P. Horton, H. Jones, and H. Griffiths. 2002. Linking drought-resistance mechanisms to drought avoidance in upland rice using a QTL approach: progress and new opportunities to integrate stomatal and medophyll responses'. *Journal of Experimental Botany* 53(371): 989–1004.

Schafleitner, R., R. Gutierrez, R. Espino, A. Gaudin, and J. Perez. 2007. Field screening for variation of drought tolerance in *Solanum tuberosum*L. by agronomical, Physiol., Genet. and Anal. *Potato Research* 50: 71–85.

Shakeel, A.A., Long-Chang-Wang Xiao-yuXie, F.S. Muhammad, Chen Man, and Lei Wang. 2011. Morphological, physiological and biochemical responses of plants to drought stress. *African Journal of Agricultural Research* 6(9): 2026–2032.

Shao, H.B., L.Y. Chu, C.A. Jaleel, P. Manivannan, R. Panneerselvam, and M.A. Shao. 2009. Understanding water deficit stress-induced changes in the basic metabolism of higher Plants-biotechnologically and sustainably improving agriculture and the eco environment in arid regions of the globe. *Critical Reviews of Biotechnology* 29: 131–151.

Wandiga, 2004. Vulnerability to climate induced highland malaria in East Africa. Report of the Assessment of Impacts and Adaptation to Climate Change in Multiple Regions and Sectors (AIACC) Project.

Yaqoob, M. 2007. Chickpea (*Cicerarietinum*L) germplasm screening and evaluation under drought prone environment. Post doctoral technical progress report. Pp.21